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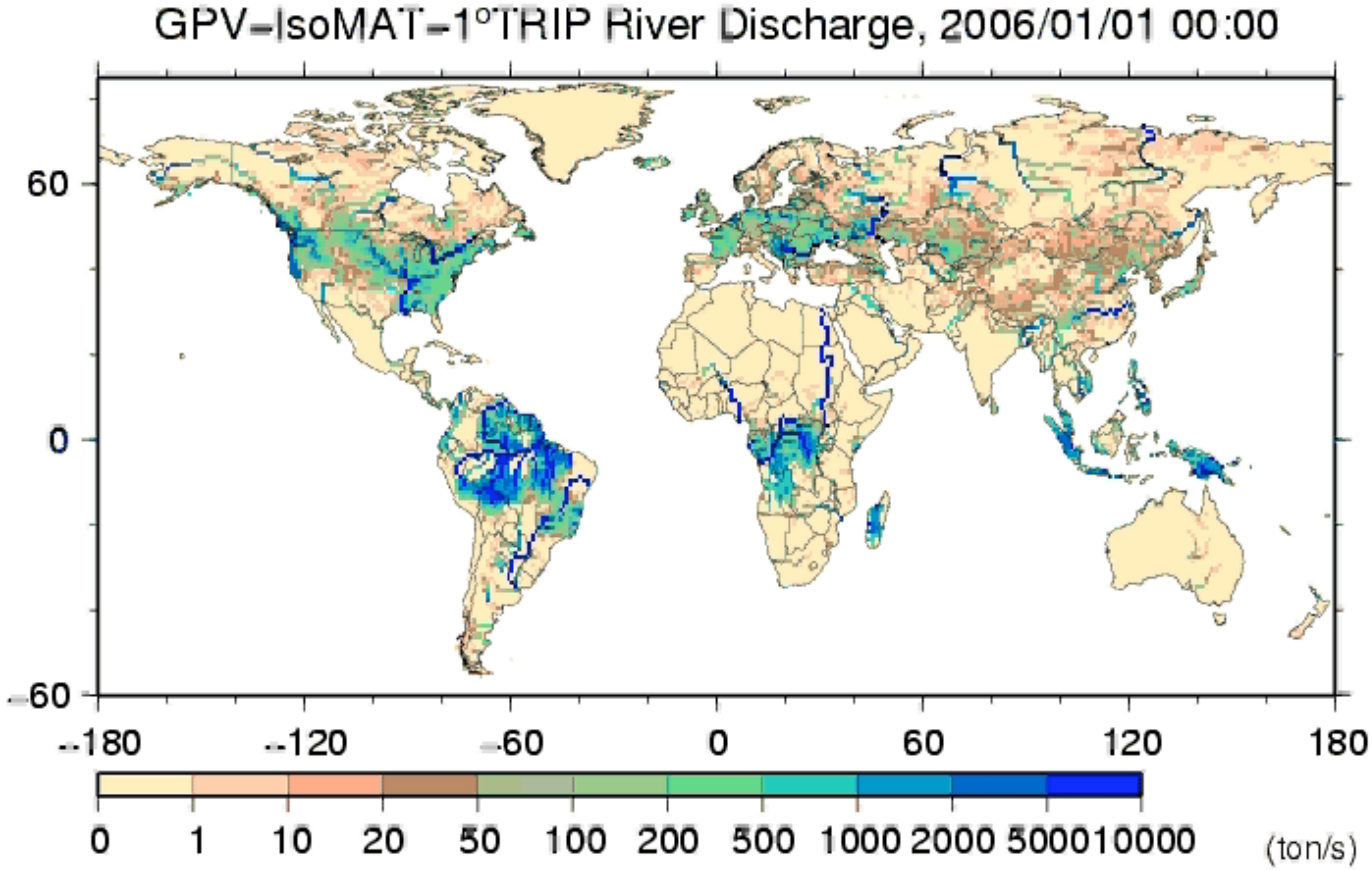
What can we suggest about global water cycles based on offline simulations of land surface models?

Taikan Oki
Institute of Industrial Science, University of Tokyo

Satellite Observations of Global Water Cycle, Beckman Center, Irvine, CA, March, 09, 2007



(6-hourly River Discharge from Today's Earth)

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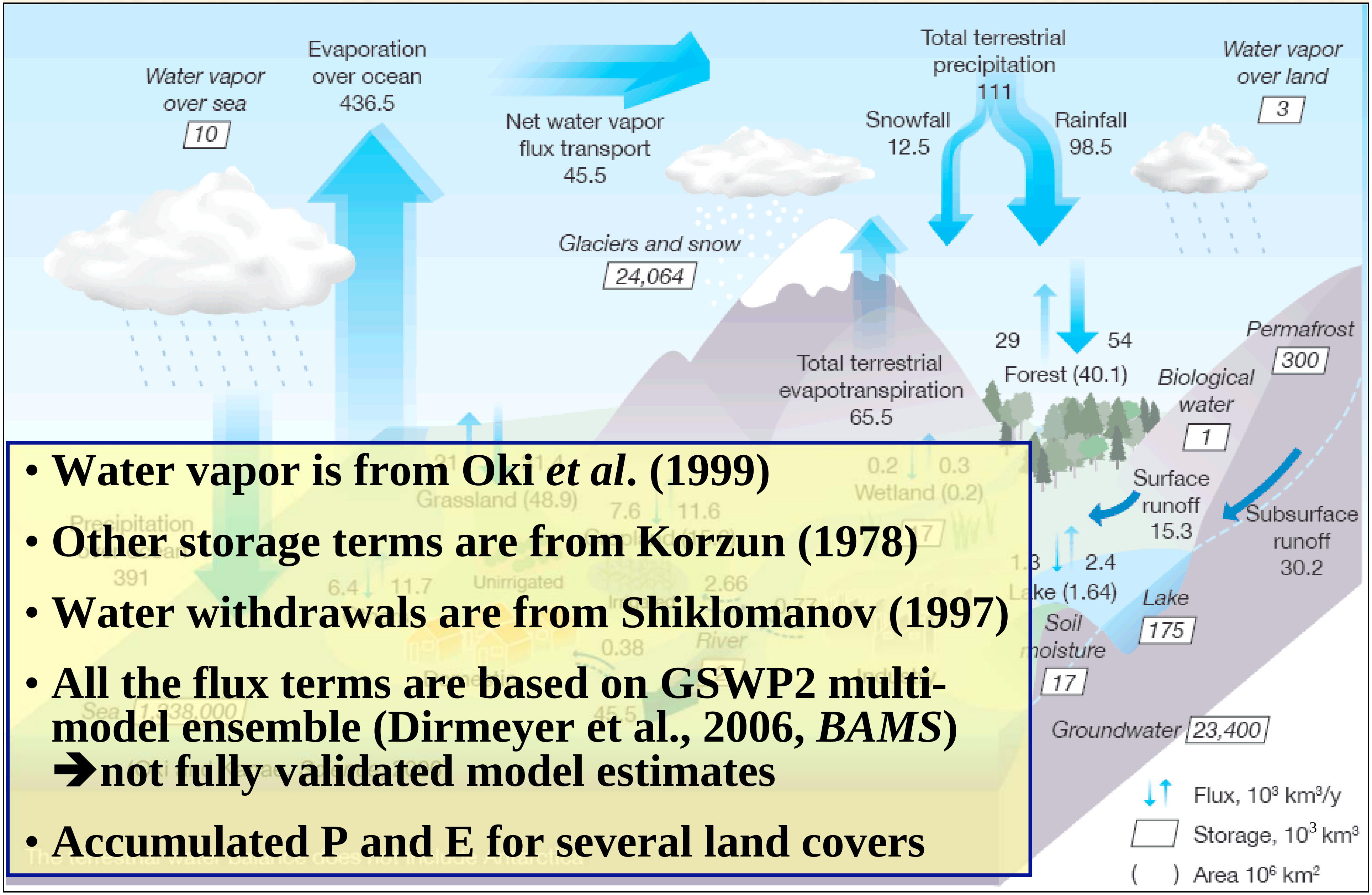
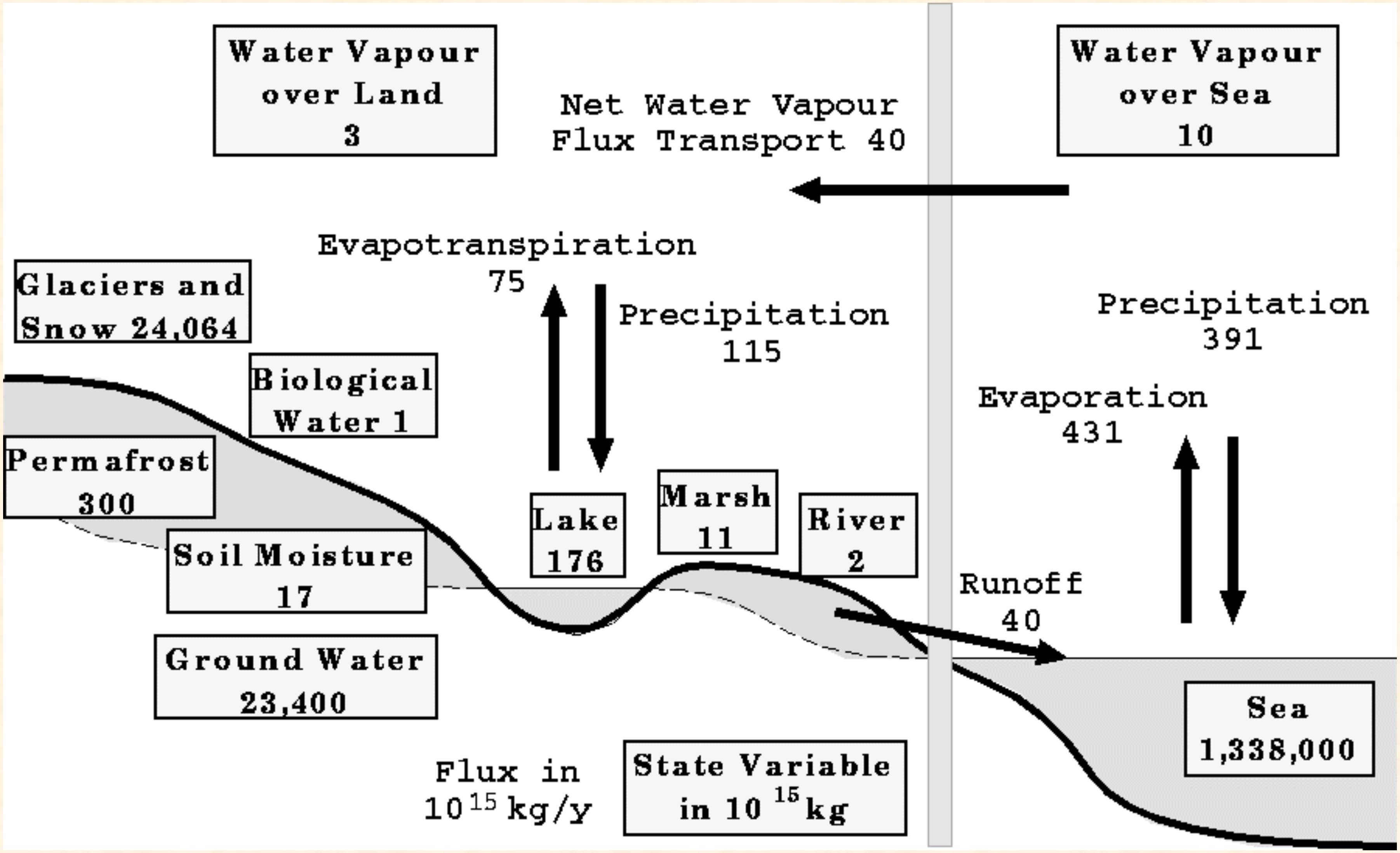
Synthesized Global Water Cycle



- **Water vapor is from Oki *et al*. (1999)**
- **Other storage terms are from Korzun (1978)**
- **Water withdrawals are from Shiklomanov (1997)**
- **All the flux terms are based on GSWP2 multi-model ensemble (Dirmeyer et al., 2006, *BAMS*) ➔not fully validated model estimates**
- **Accumulated P and E for several land covers**

Storage and Flux in Water Cycles



(Oki, *Global Energy and Water Cycles*, CAP 1999)

Why not using GSWP2 data?

- **Major Goal of GSWP2: Produce the "best" global data sets of soil moisture, surface fluxes, and related hydrologic quantities (including runoff) for 1986-1995 with 1x1 degree grid spacing considering the <u>uncertainties</u> associated with**
  - **Land surface models: more than 10 LSMs**
  - **Model parameters: 2 kinds of vegetation, etc.**
  - **Forcing data: 3 kinds of reanalysis data, corrected precipitation, etc.**
  - **Temporal and spatial scales to run LSMs**

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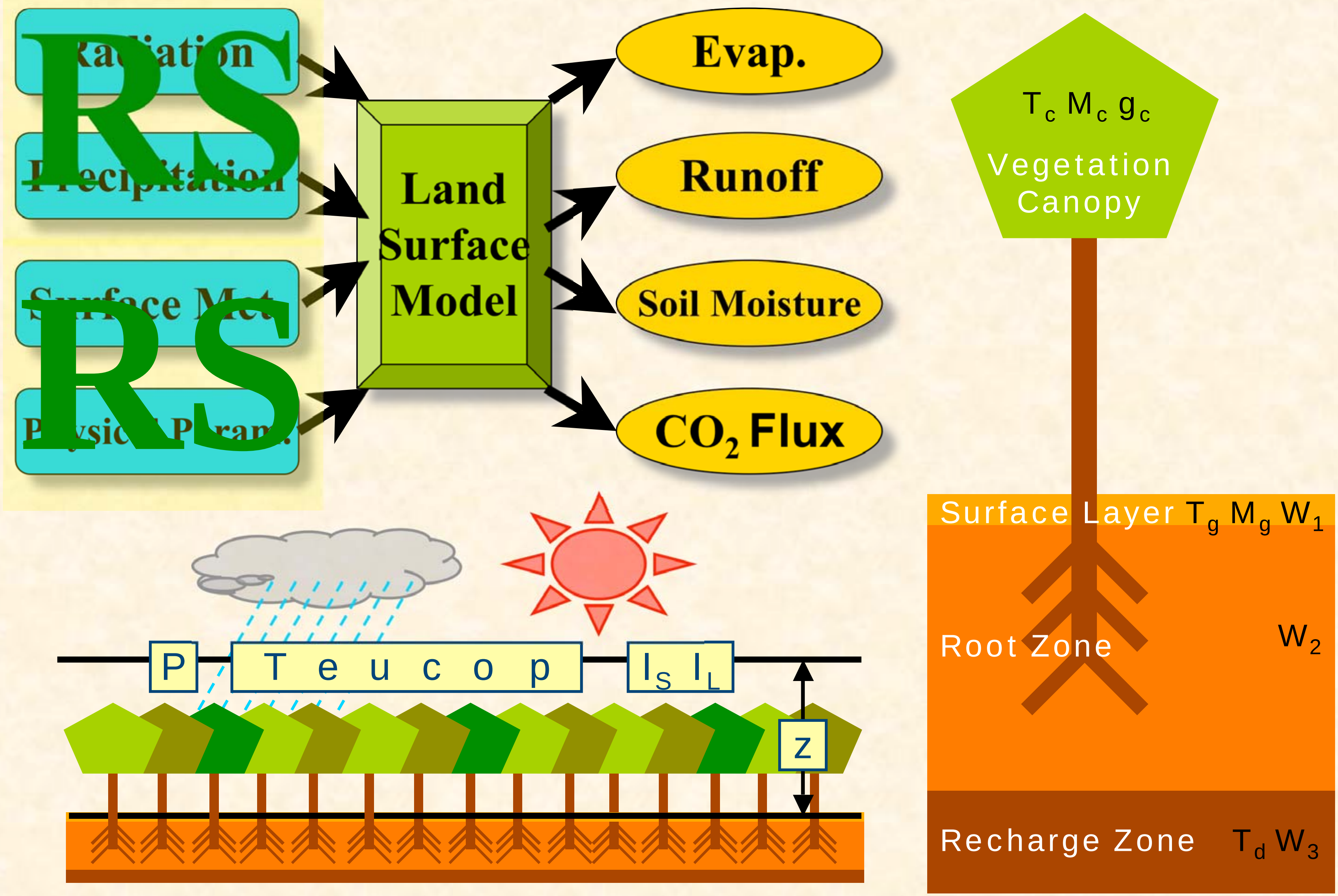
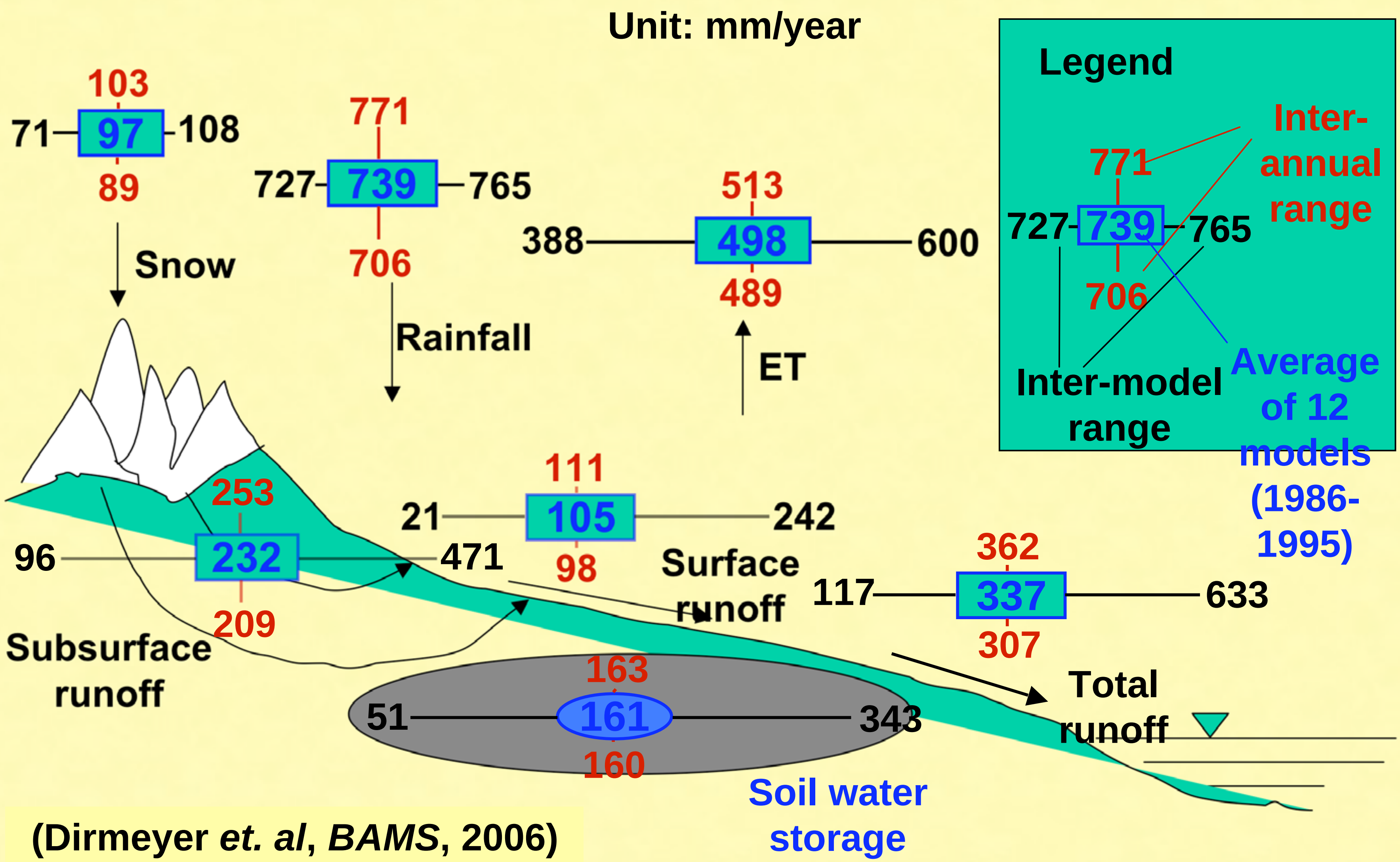
Offline Simulation of LSMs

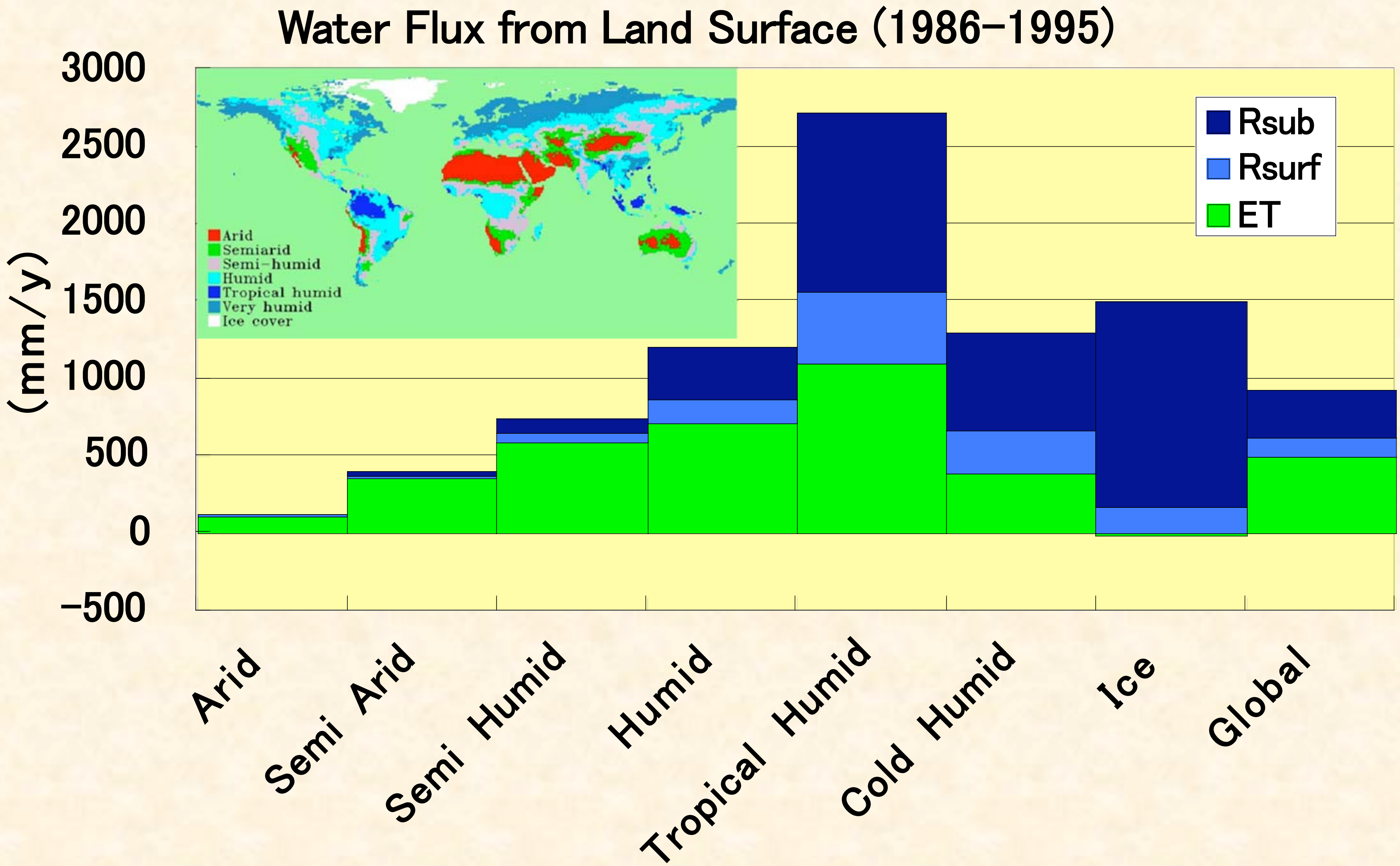


Global Terrestrial Water Budget

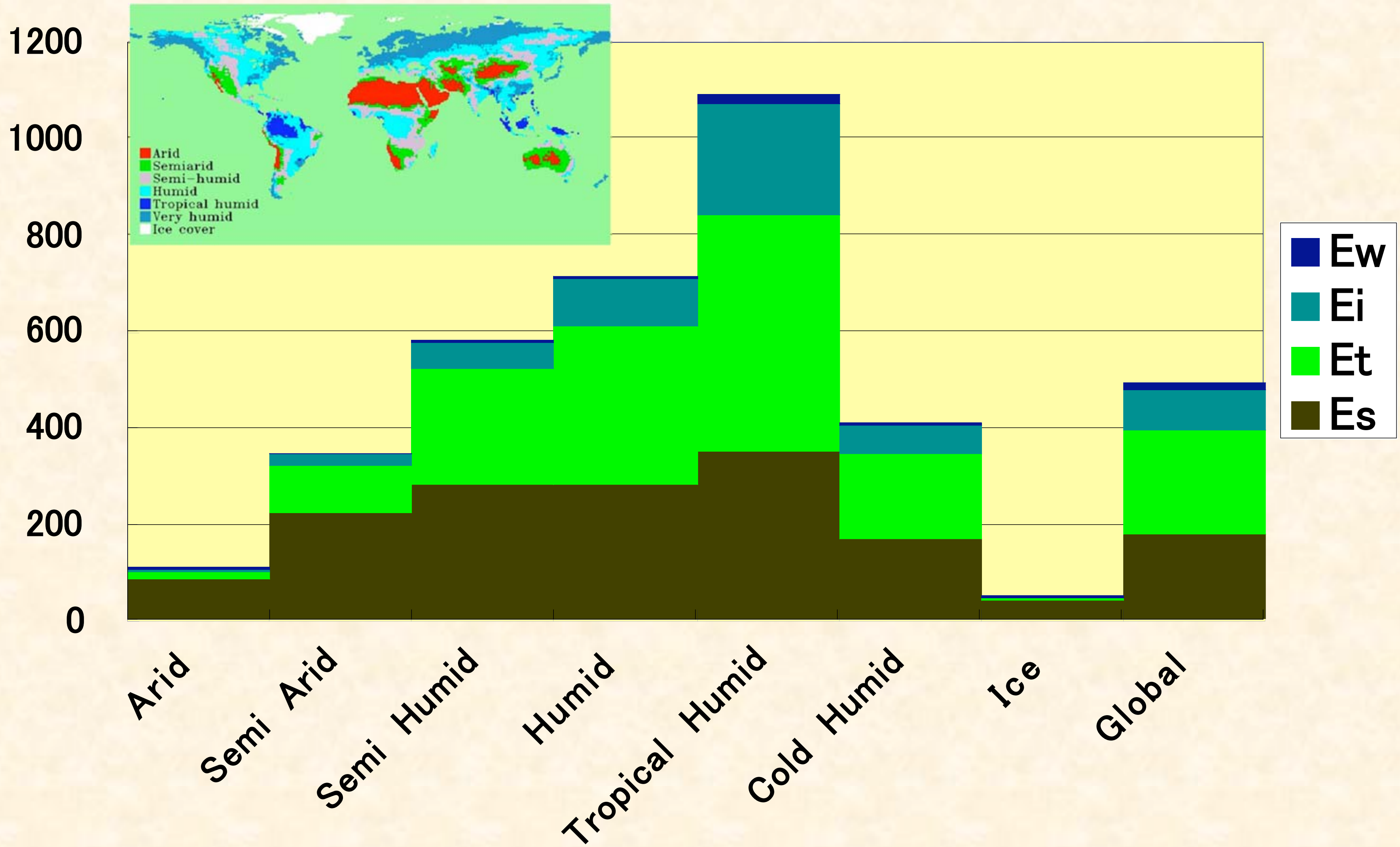


(Dirmeyer *et. al*, *BAMS*, 2006)

Mean Water Balance (mm/y)



Mean Evapotranspiration (mm/y)



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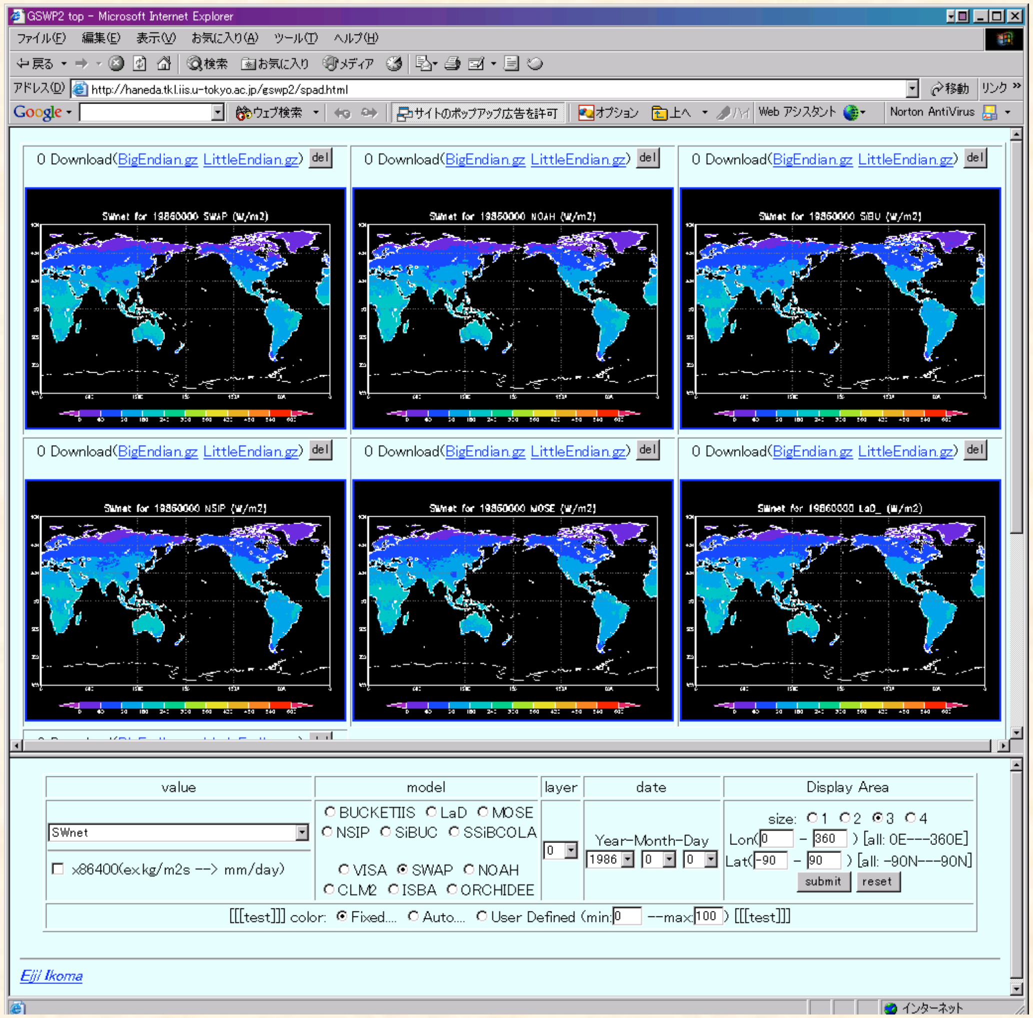
GSWP2 data is ready to be used!



- Time step:
  - Daily
  - Monthly mean
  - Annual mean
- Color bar:
  - Automatic
  - User specified max. and min.
- 4 figure sizes
- Unit conversion from kg/m2/s to mm/day

http://gswp2.tkl.iis.u-tokyo.ac.jp/gswp2/

You can display several figures at once and compare.
You can also save the data in GrADS friendly format☺

The GSWP2-ICC GUI is scale independent!
If you have a big screen, you can display many figures at once and enjoy the modern map discussion!

http://gswp2.tkl.iis.u-tokyo.ac.jp/gswp2/

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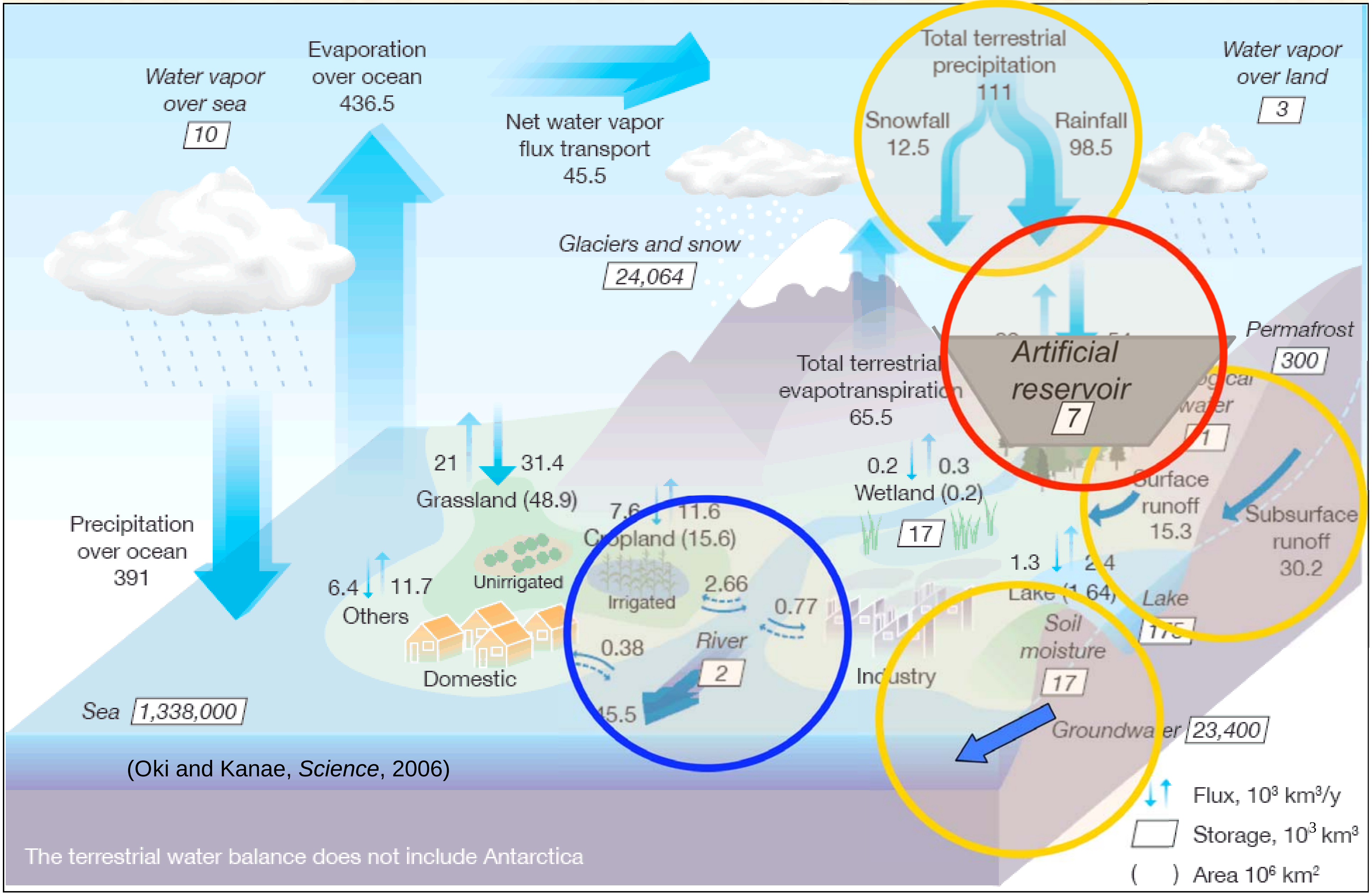
Synthesized Global Water Cycle



(Oki and Kanae, *Science*, 2006)

Real issue is: why on *Science*?

A special section of freshwater resources was planned --- it should reflect the interests and expectations from society in the R&D on global freshwater resources.

FRESHWATER RESOURCES

REVIEW

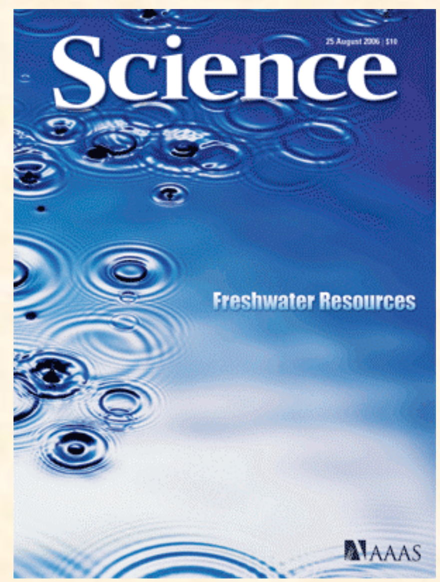
Global Hydrological Cycles and World Water Resources

Taikan Oki[1,2,3]*† and Shinjiro Kanae[1,4]*

Water is a naturally circulating resource that is constantly recharged. Therefore, even though the stocks of water in natural and artificial reservoirs are helpful to increase the available water resources for human society, the flow of water should be the main focus in water resources assessments. The climate system puts an upper limit on the circulation rate of available renewable freshwater resources (RFWR). Although current global withdrawals are well below the upper limit, more than two billion people live in highly water-stressed areas because of the uneven distribution of RFWR in time and space. Climate change is expected to accelerate water cycles and thereby increase the available RFWR. This would slow down the increase of people living under water stress; however, changes in seasonal patterns and increasing probability of extreme events may offset this effect. Reducing current vulnerability will be the first step to prepare for such anticipated changes.

All organisms, including humans, require water for their survival. Therefore, ensuring that adequate supplies

from liquid to gas and eventually recondenses as a liquid. Water assimilated during photosynthesis becomes part of carbohydrates stored in



How can we contribute?

- **Hydrological science will contribute for society by providing *reliable*….**
  - 4 **dataset of past and current global hydrological cycles,**
  - 5 **near-real time to seasonal prediction of natural variability of climate, such as ENSO, and**
  - 3 **projection of the change in hydrological cycles under climate change conditions, such as global warming.**
- **Hydrological science will contribute for society by giving answers to….**
  - 1 **Quantitative estimates how much water is (and will be) really available for further water withdrawal for human beings, ← needs prediction of societal part, as well.**
  - 2 **Alternative measures to be taken in order to secure the water supply to meet the demand, such as promoting virtual water trade instead of domestic production.**

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How to Assess

Not from RS

Climate Model
River Map (TRIP)

Water Resources Q

Country Statistics
Grid Data

W Water Withdrawal

Balance (Water Scarcity Index)

$R_{ws} = (W-S)/Q$

- <0.1 : No Stress
- 0.1—0.2 : Low Stress
- 0.2—0.4 : Moderate St.
- 0.4< : High Stress

$A_{wc} = Q/C$ $(m^3/y/c)$

- \>1700 : No Stress
- 1700-1000 : Low Stress
- 1000-500 : Moderate St.
- 500> : High Stress

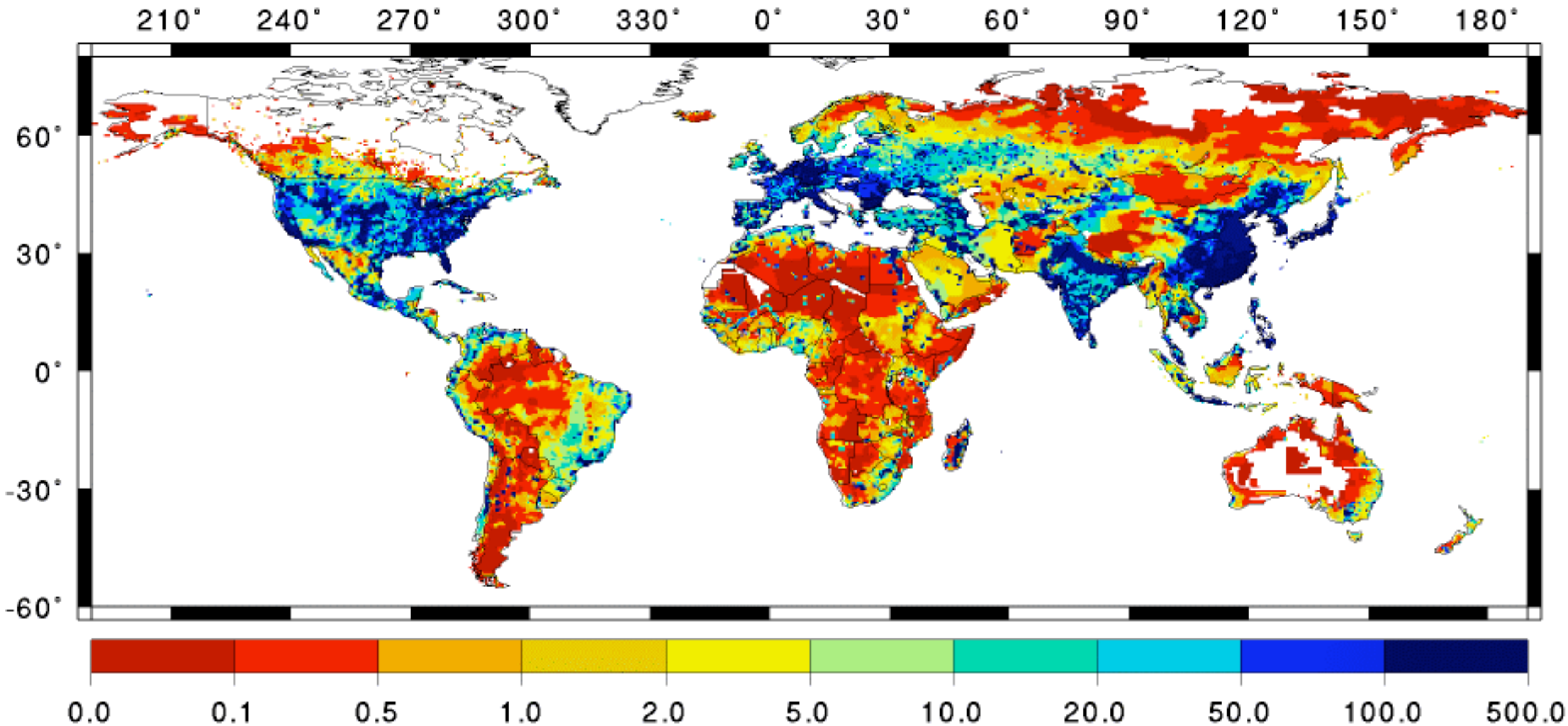
Water Res. Assessment

(Oki, et. al, 2001, HSJ)

Annual Total Freshwater Withdrawal

Irrigation-area base. [10^6 m^3/year/0.5°grid]

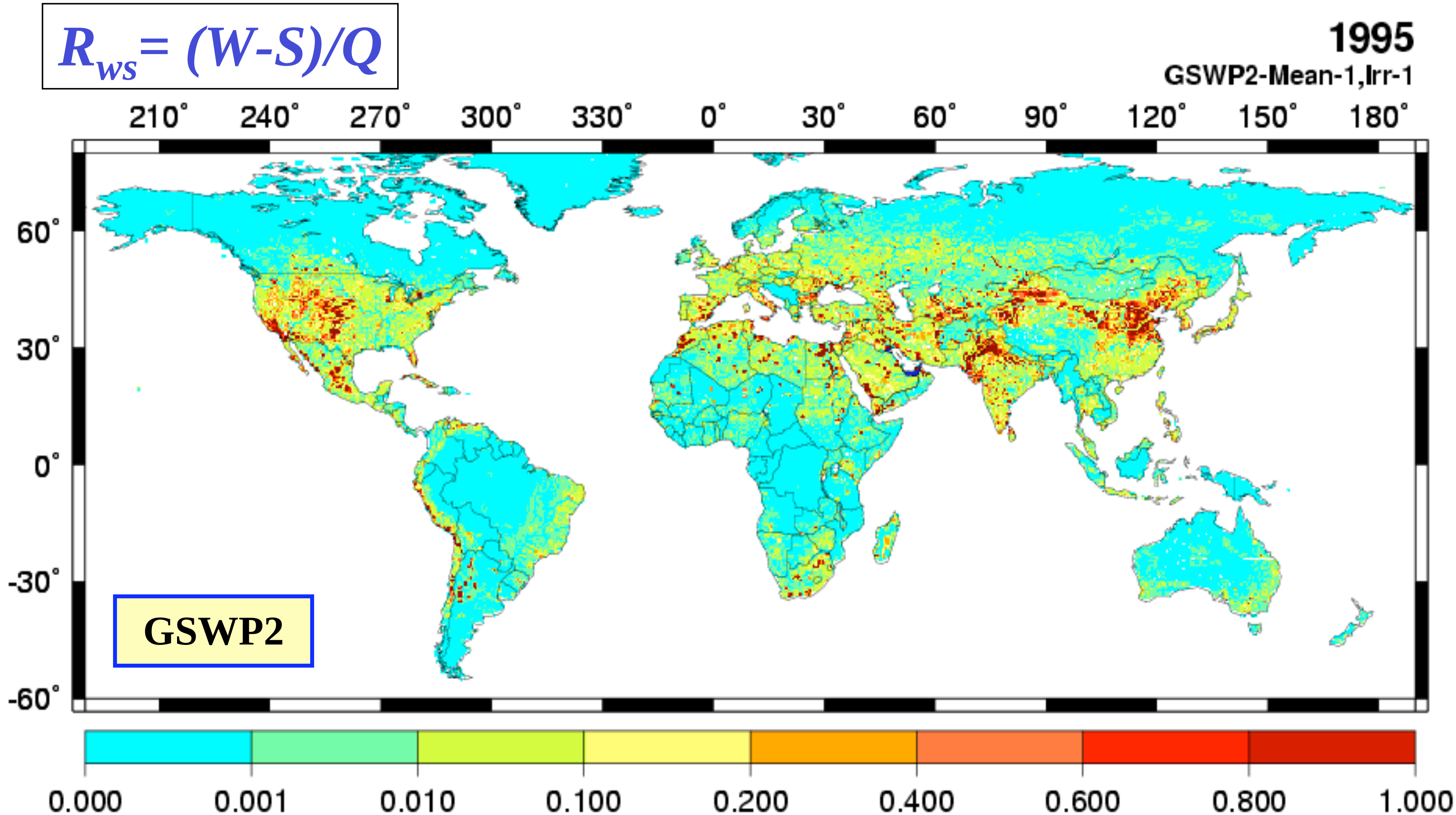
1995



(Oki, et. al, 2001, HSJ)

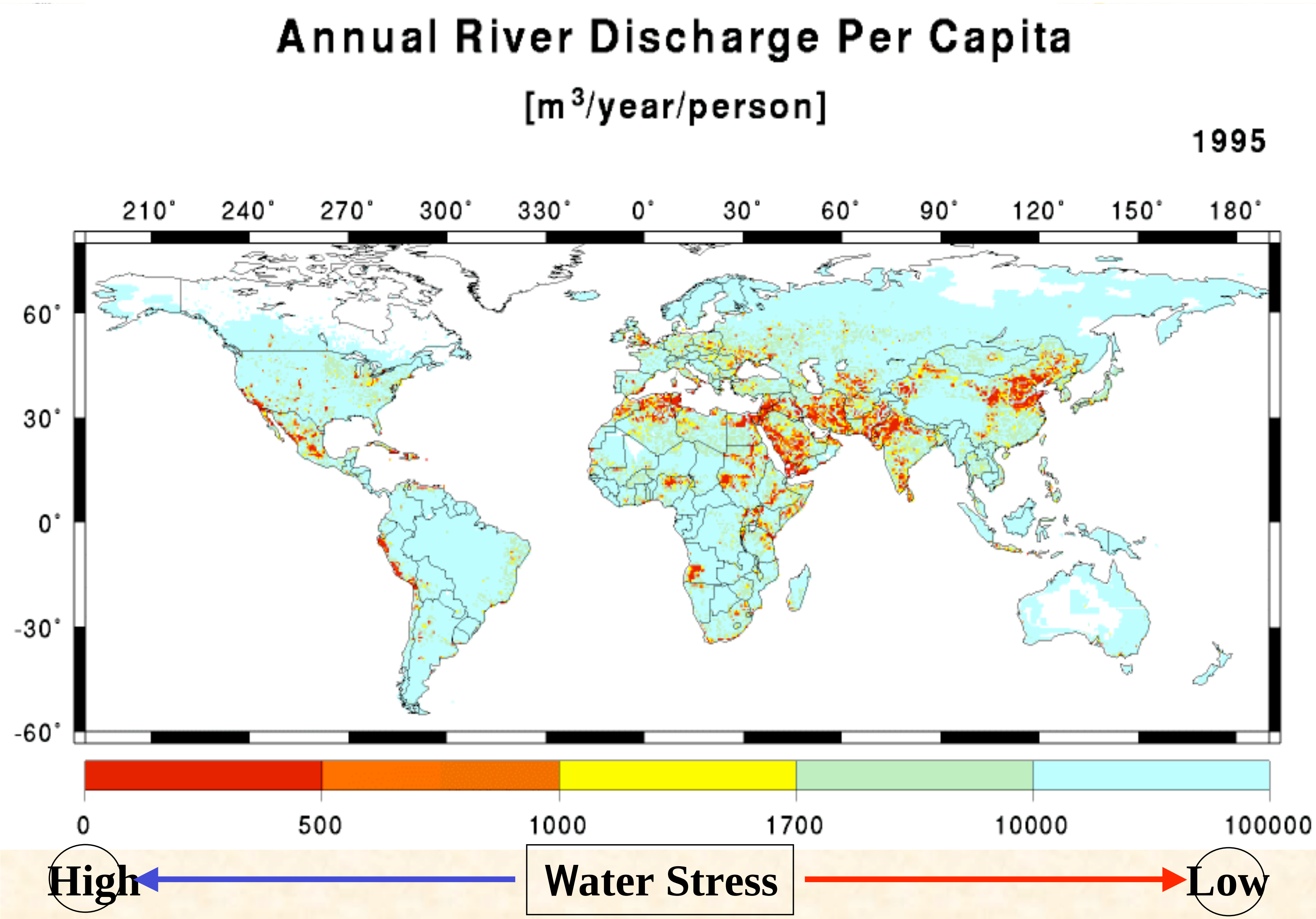
Annual Withdrawal-to-Availability Ratio

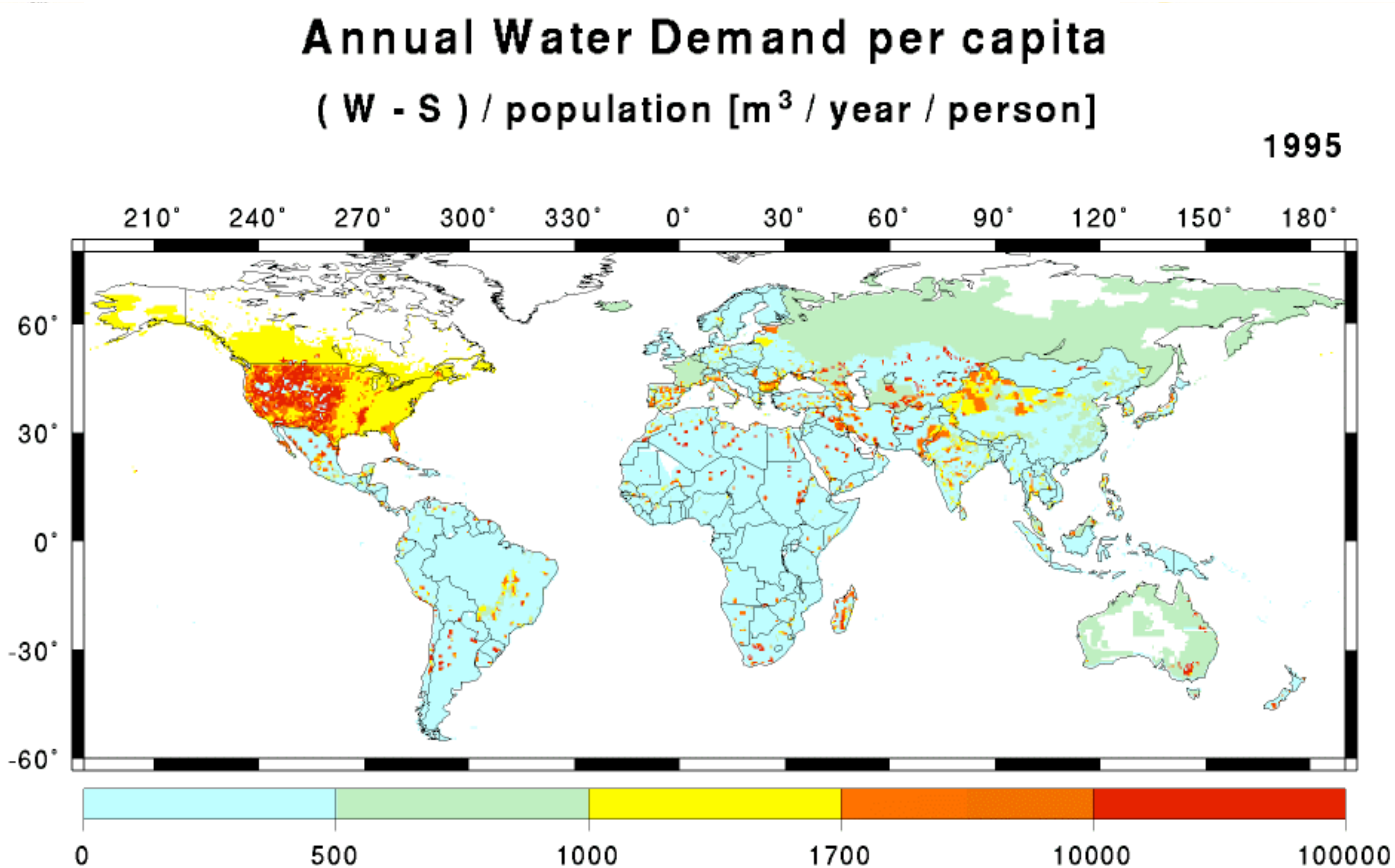
$R_{ws} = (W-S)/Q$



Low ← **Water Stress** → High

(Oki, et. al, 2001, HSJ)®


Annual River Discharge Per Capita
[m³/year/person]
1995
210° 240° 270° 300° 330° 0° 30° 60° 90° 120° 150° 180°
60° 30° 0° -30° -60°
0 500 1000 1700 10000 100000
High
Water Stress
Low



R_{ws}= $(W\text{-}S)/Q$ and A_{wc}= Q/C($m^3/y/c$) have similar global distribution → Is $(W\text{-}S)/C$ globally uniform?

How can we contribute?

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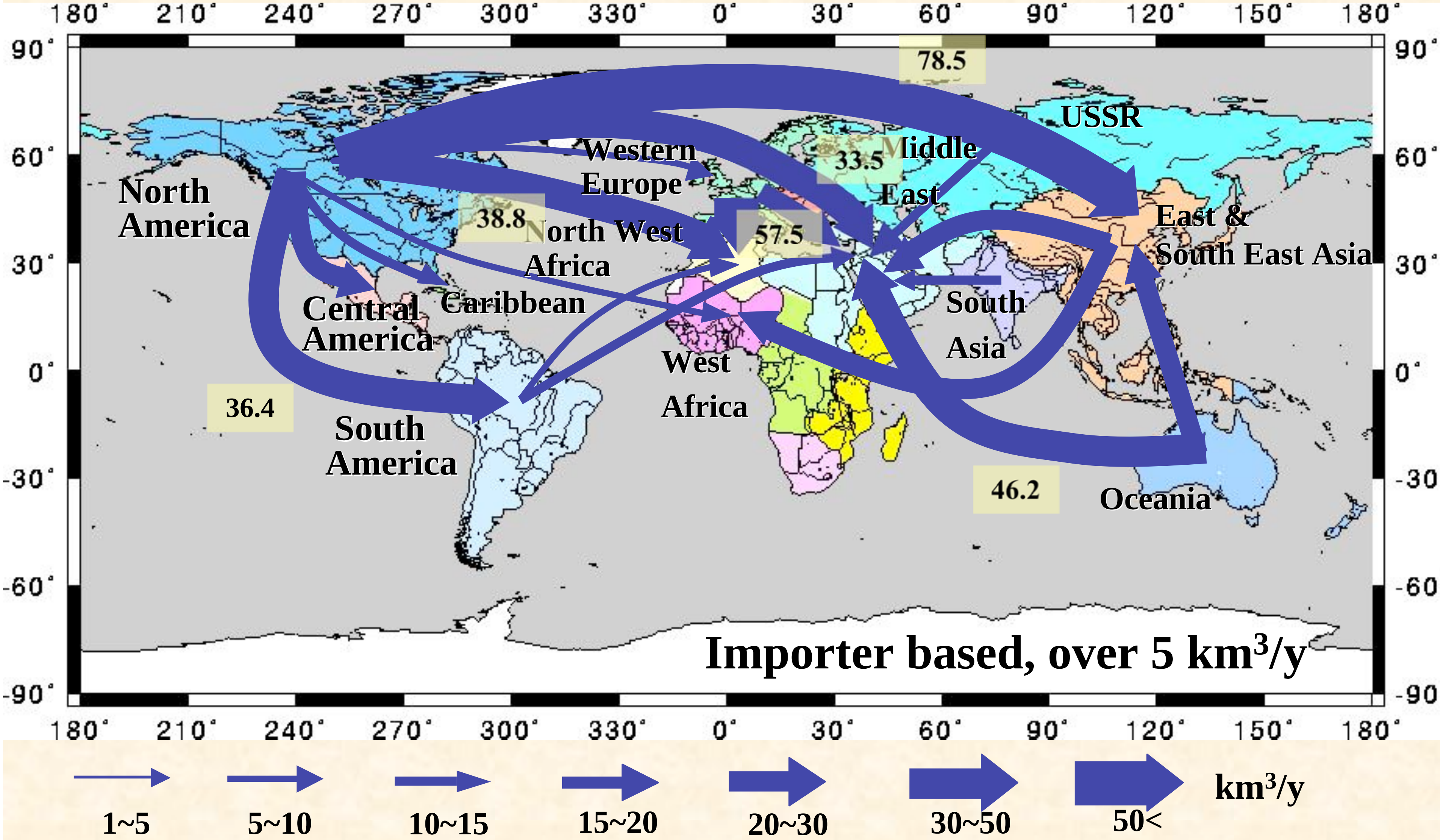
"Virtually Required Water" Trade between Regions associated with food trade in 2000 (cereals only)



(Oki, et. al, 2004)

(Based on Statistics from FAO etc., for 2000)

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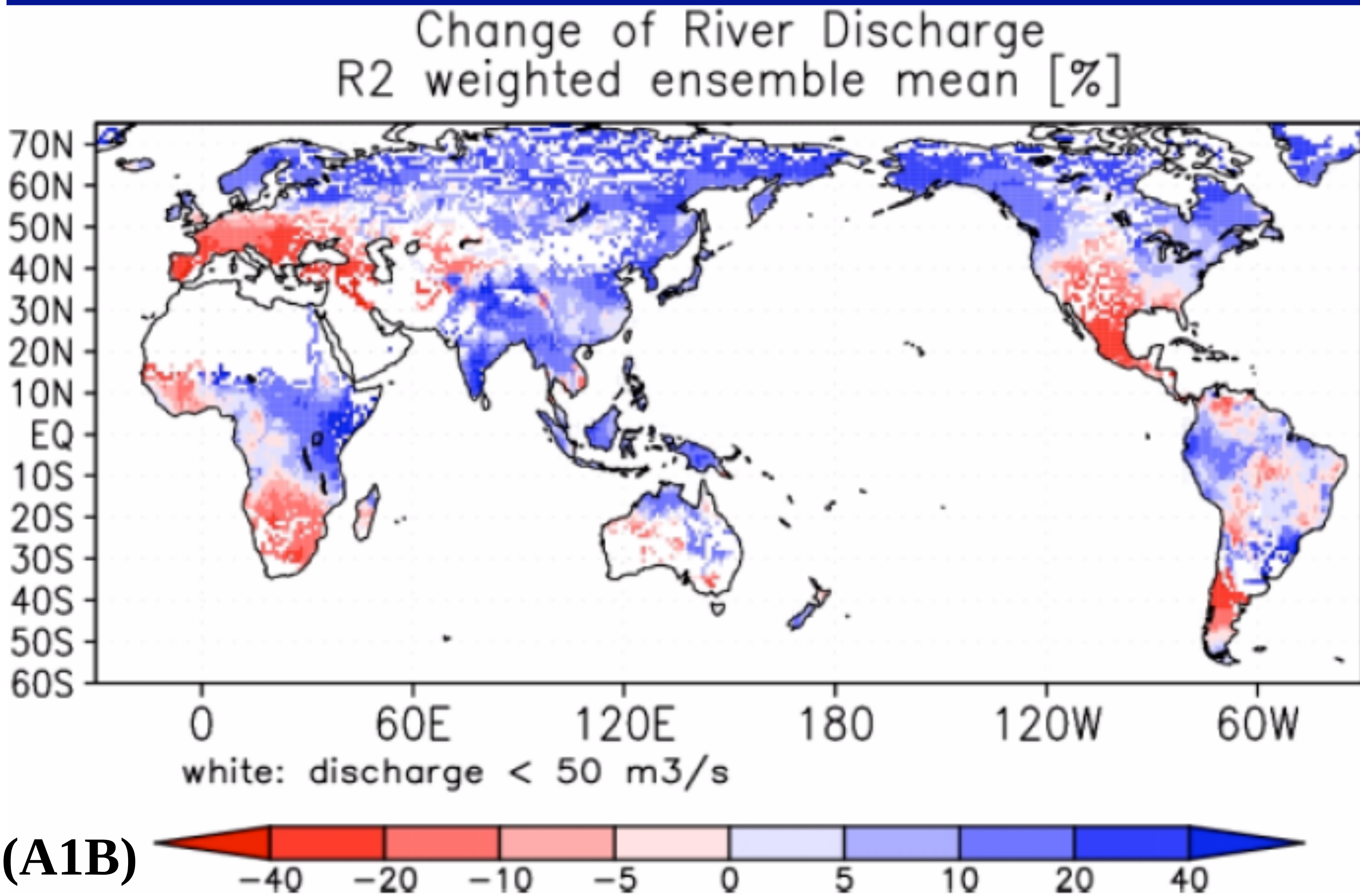
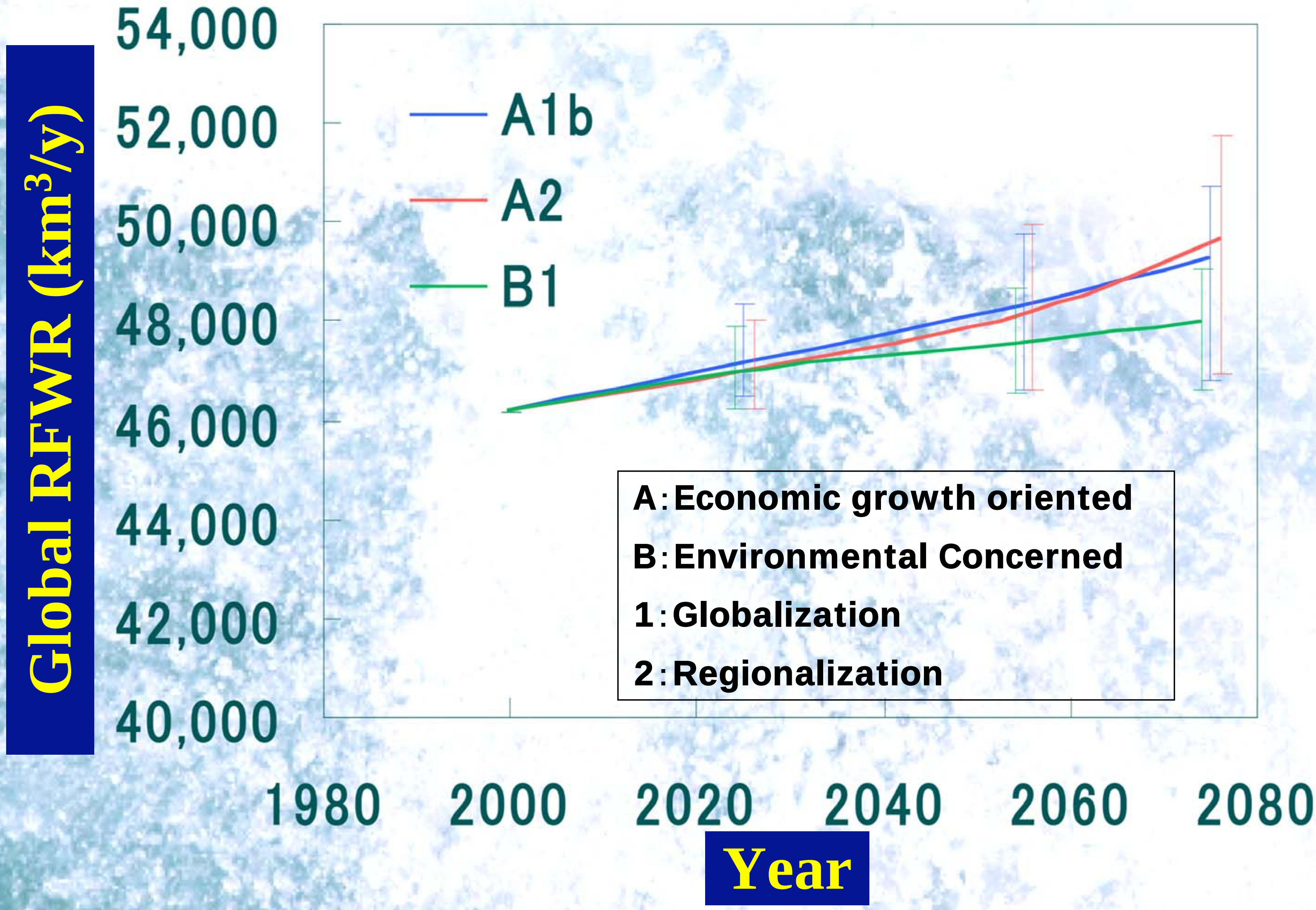
Multi-model Ensemble Projection
---15 GCM results for IPCC AR4 ---



(A1B)

(Nohara, et. al, 2006, *J Hydrometeor.*)

Global Renewable Freshwater Resources



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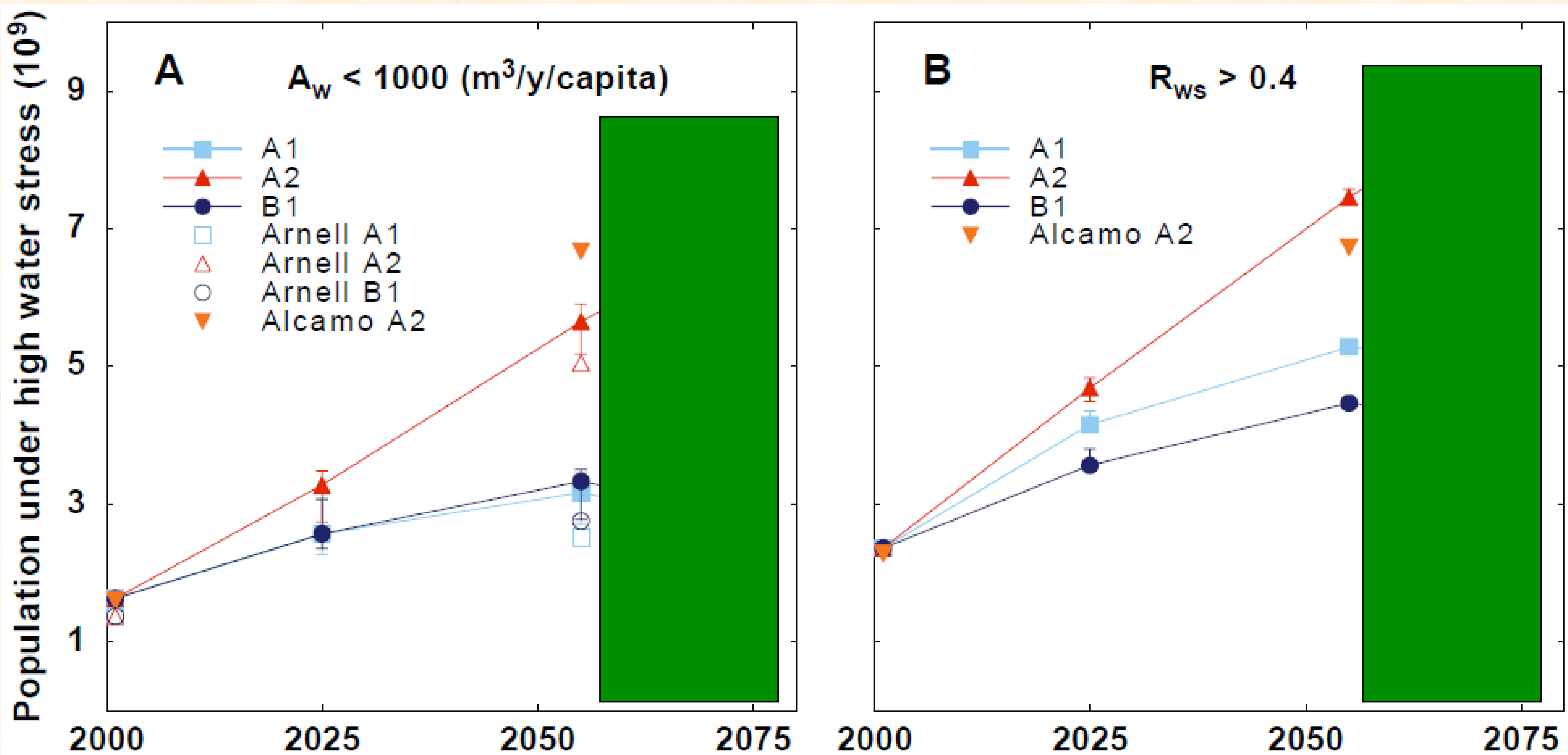
Future Projection through the 21st Century

Changes considered include:

- **Water demand for domestic, industrial, and irrigation sectors.**
  - **Population (SRES)**
    - **Urban and rural areas separated**
  - **GDP (SRES)**
  - **Improvement of reuse (SRES)**
- **Climate change (SRES)**

Not from RS

Number of people under serious water stress



(Oki and Kanae, *Science*, 2006)

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Groisman1994:

Satellite-derived SNOW AREA in spring (AM) is decreasing at North America and East Asia （1973-1993）

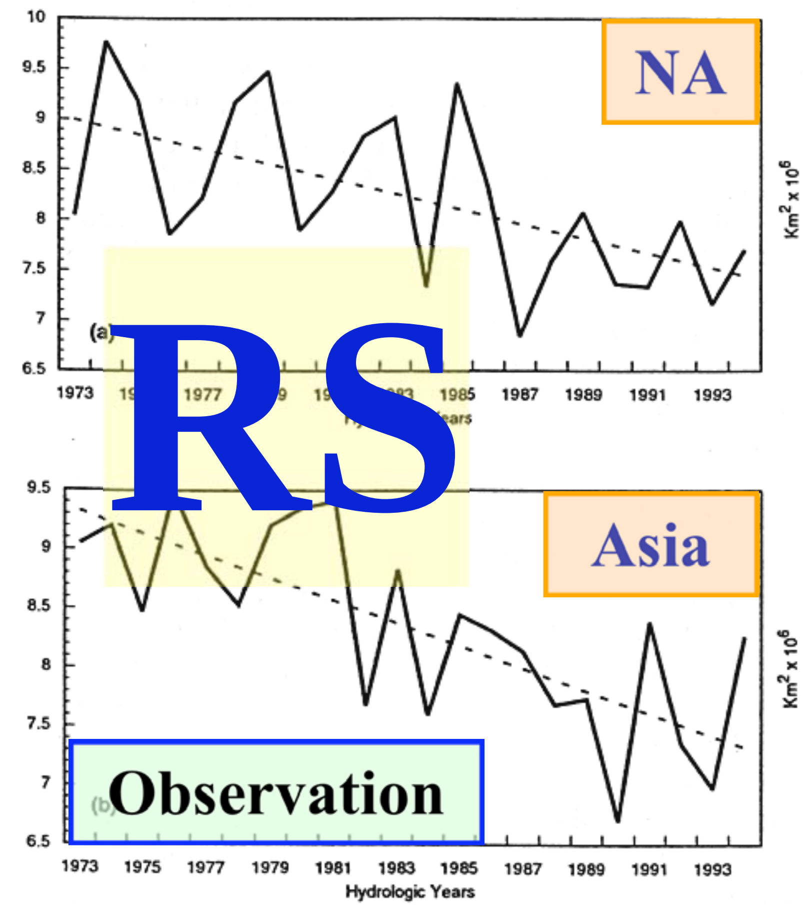
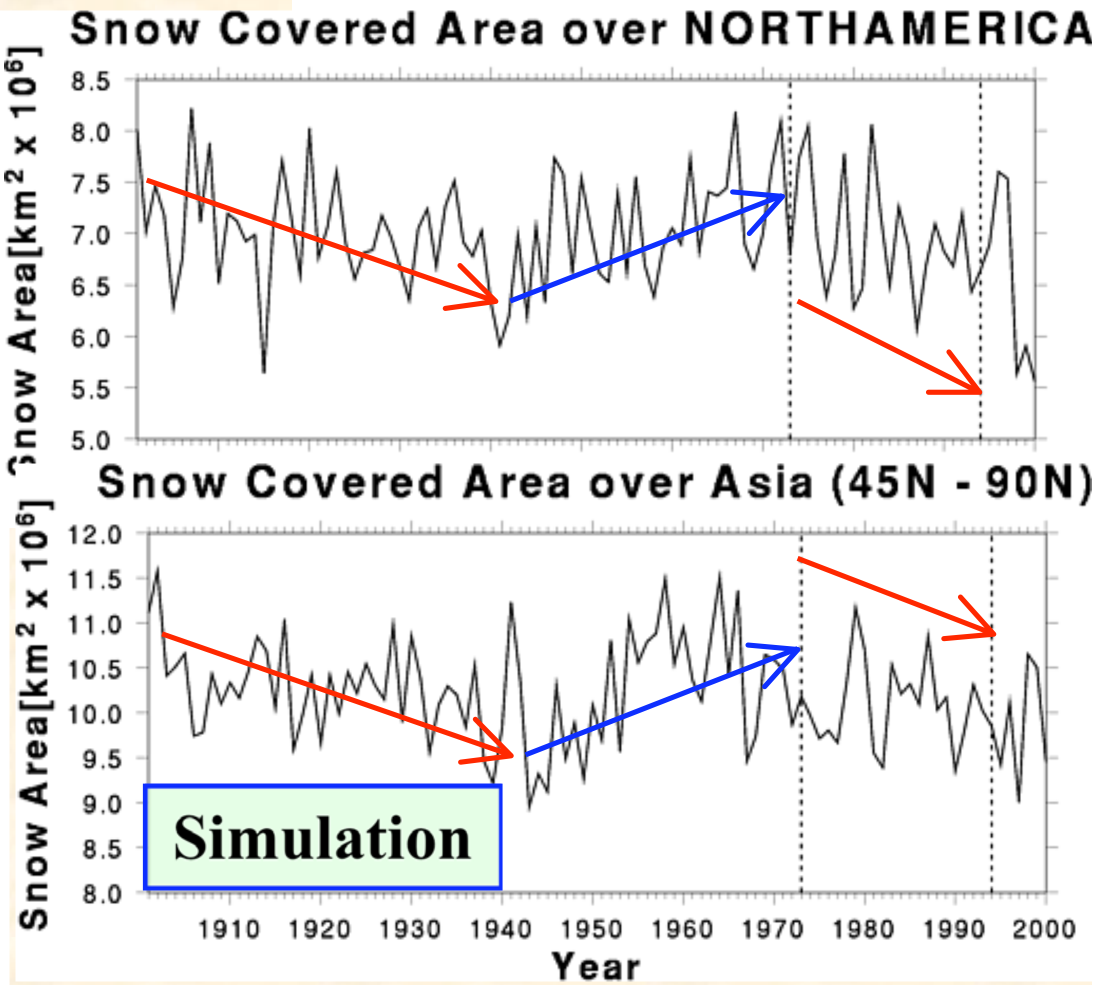


FIG. 14. Spring snow cover extent (updated to 1994) over (a) North America and (b) east Asia and their linear trends.



(Hirabayashi *et al*., *JGR*, 2005)

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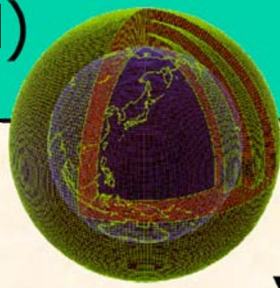
Today's Earth

Model Forecasts (JMA/GSM)



- Quasi-real-time prediction system
- 6hourly (up to 84 hours ahead)
- 1x1 degree lon.-lat. globally
- http://hydro.iis.u-tokyo.ac.jp/LIVE/

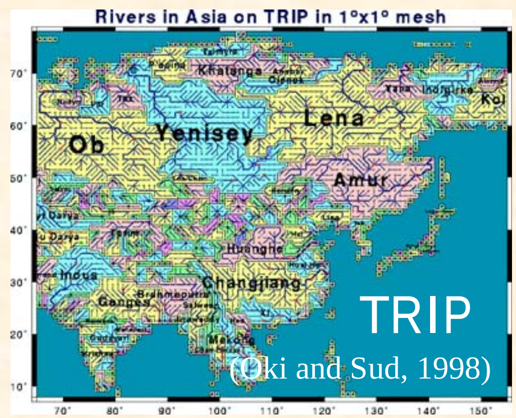
Temp. etc. → Land Surface Model (Iso-MATSIRO)

Precipitation → Land Surface Model (Iso-MATSIRO)

Precipitation → Cloud Cover → Radiation → Land Surface Model (Iso-MATSIRO)

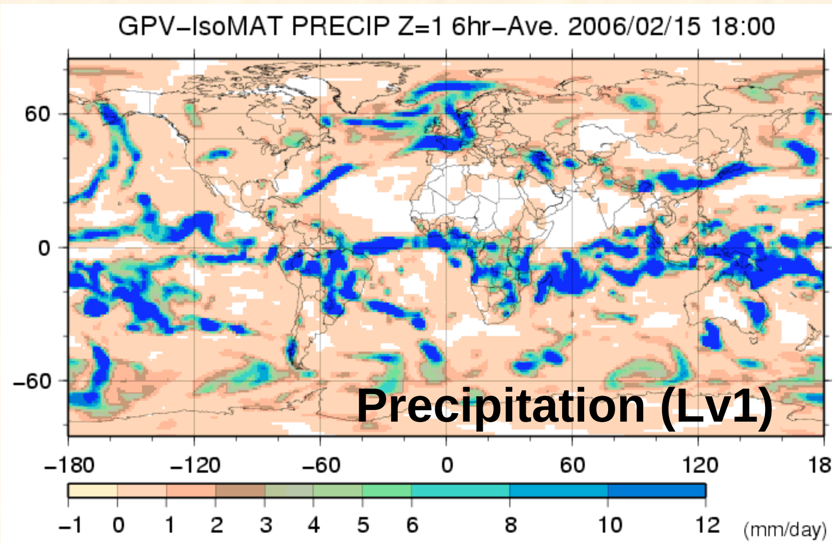
Land Surface Model (Iso-MATSIRO) → Runoff → Digital River (TRIP) → River discharge

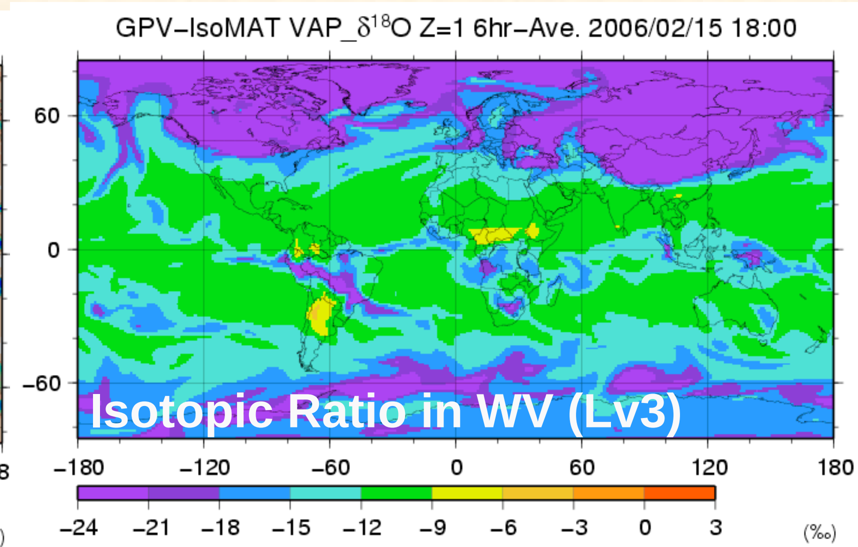
Land Surface Model (Iso-MATSIRO) → Soil moisture

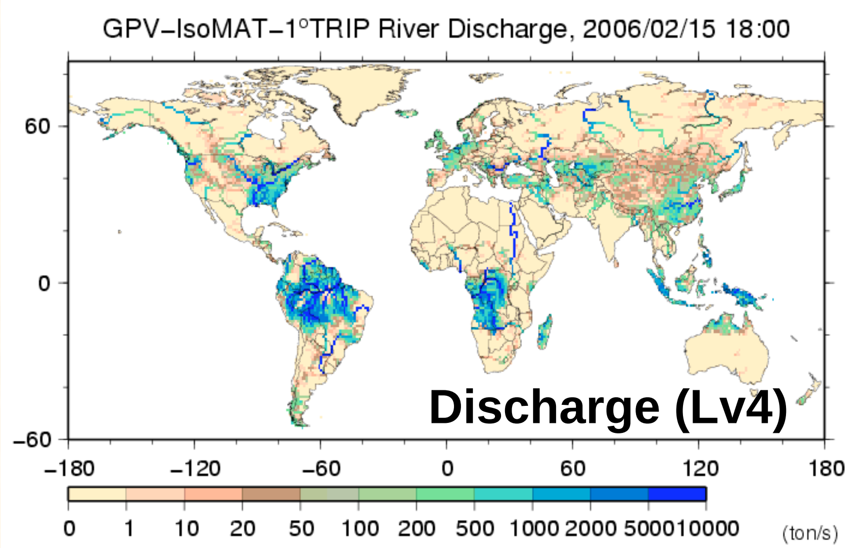


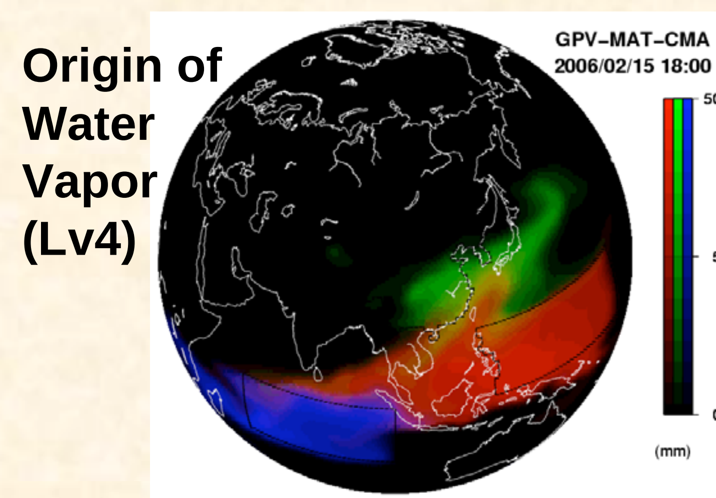
(Oki and Sud, 1998)

Today’s Earth:
http://hydro.iis.u-tokyo.ac.jp/LIVE/









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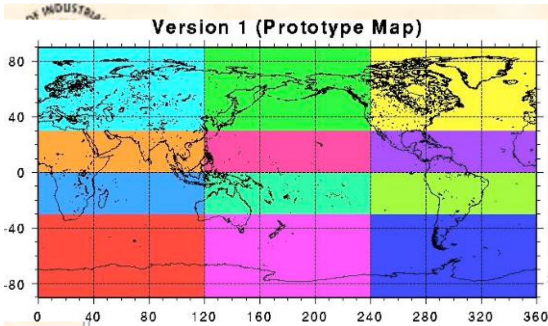
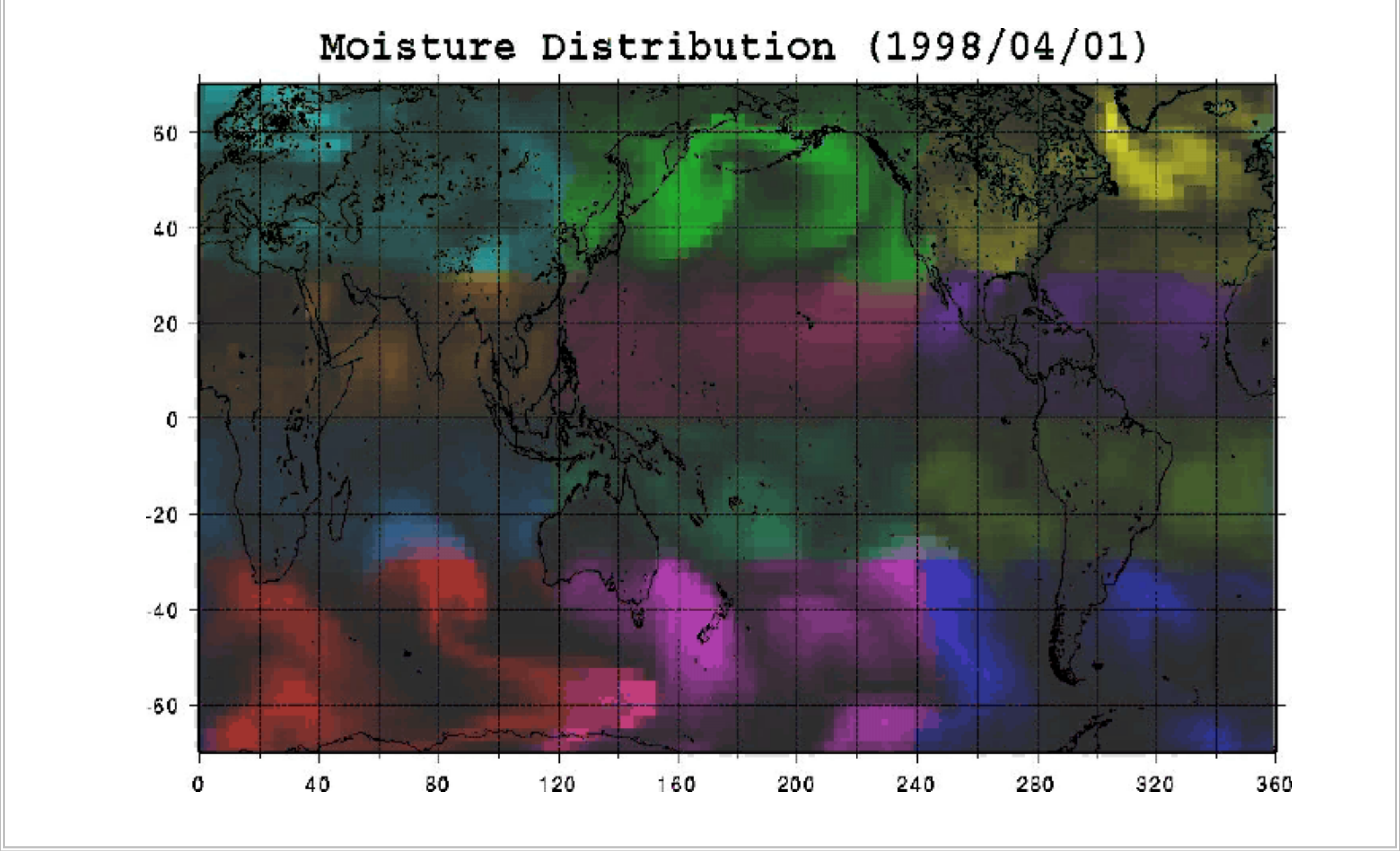
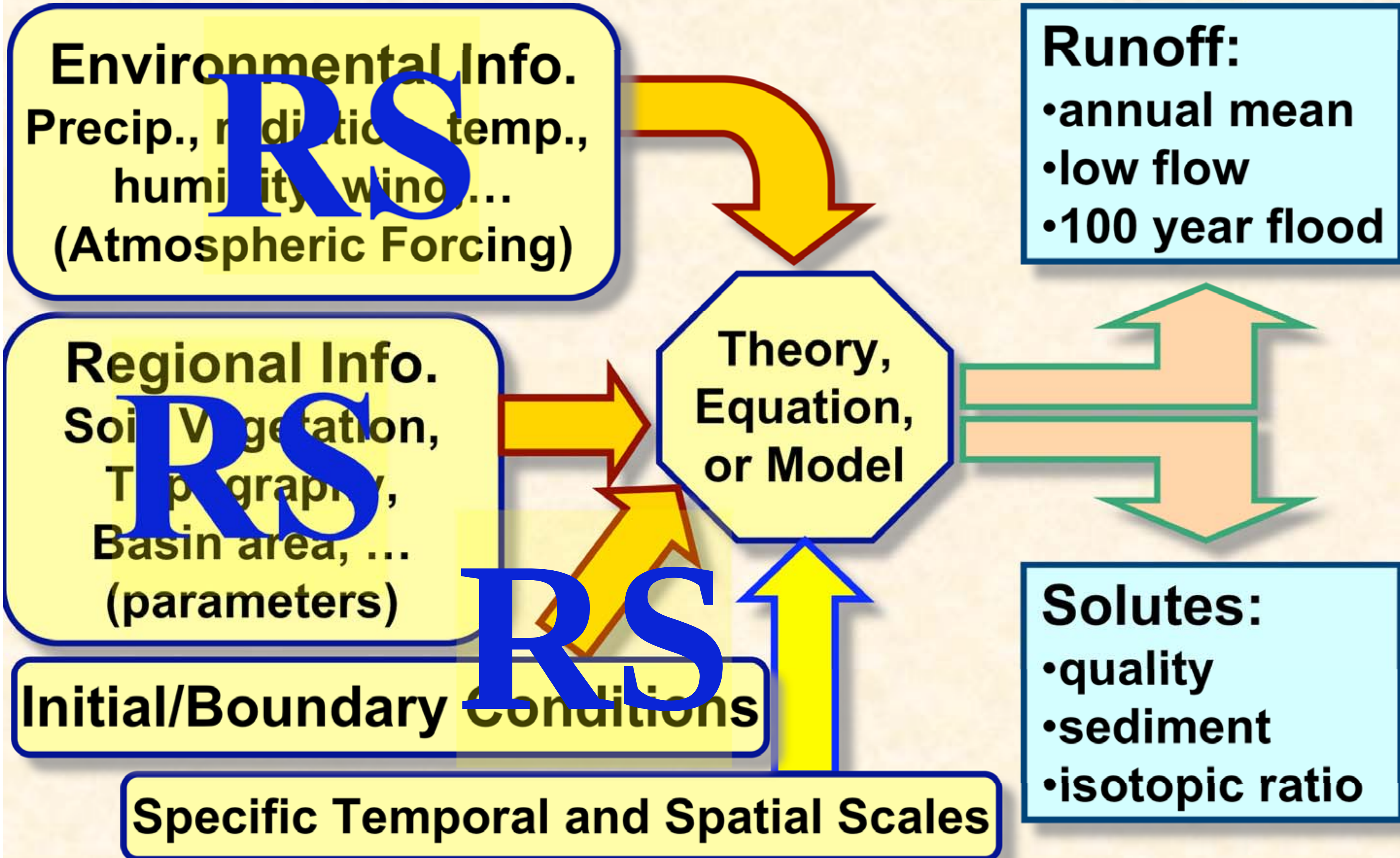
CMA Result 1:
12 tags, 1998/04/01~10/31, Globe





Sources of Uncertainties



Applicability/Accuracy may differ region by region.

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HRPP

- **Several high resolution precipitation products (HRPP) are developed using microwave radiometers (TMI,AMSRE,SSM/I…) and infrared sensors (GOES,GMS,METEOSAT…) with other information (rain gauge, the model output).**

Example of global precipitation maps

Products	Developer	spatial	temporal	MWR	IR	RG	NWP	behind RT
GPCP	WCRP/GEWEX	2.5deg	monthly	○	○	○	×	2–3mon.
CMAP	NOAA/CPC	2.5deg	5daily	○	○	○	×	1day
GPCP 1DD	NASA/GSFC	1.0deg	daily	○	○	○	×	2–3mon.
GSMaP_MWR	JST/CREST	0.25deg	6hourly	○	×	×	△	N.A.
PERSIANN	U.Arizona	0.25deg	6hourly	△	○	×	×	2days?
TRMM 3B42RT	NASA/GSFC	0.25deg	3hourly	○	○	×	×	9hours
NRL Blended	NRL	0.25deg	3hourly	○	○	×	×	?
GSMaP_MVK	JST/CREST	0.1deg	hourly	○	○	×	△	N.A.
CMORPH	NOAA/CPC	8km	30min	○	○	×	×	1day
Hydro Estimator	NOAA/NESDIS	4km	30min	×	○	○	○	10min?
SCaMPR	NOAA/NESDIS	4km	15min	○	○	×	×	?

Higher resolution

useful for *Yesterday's* Earth

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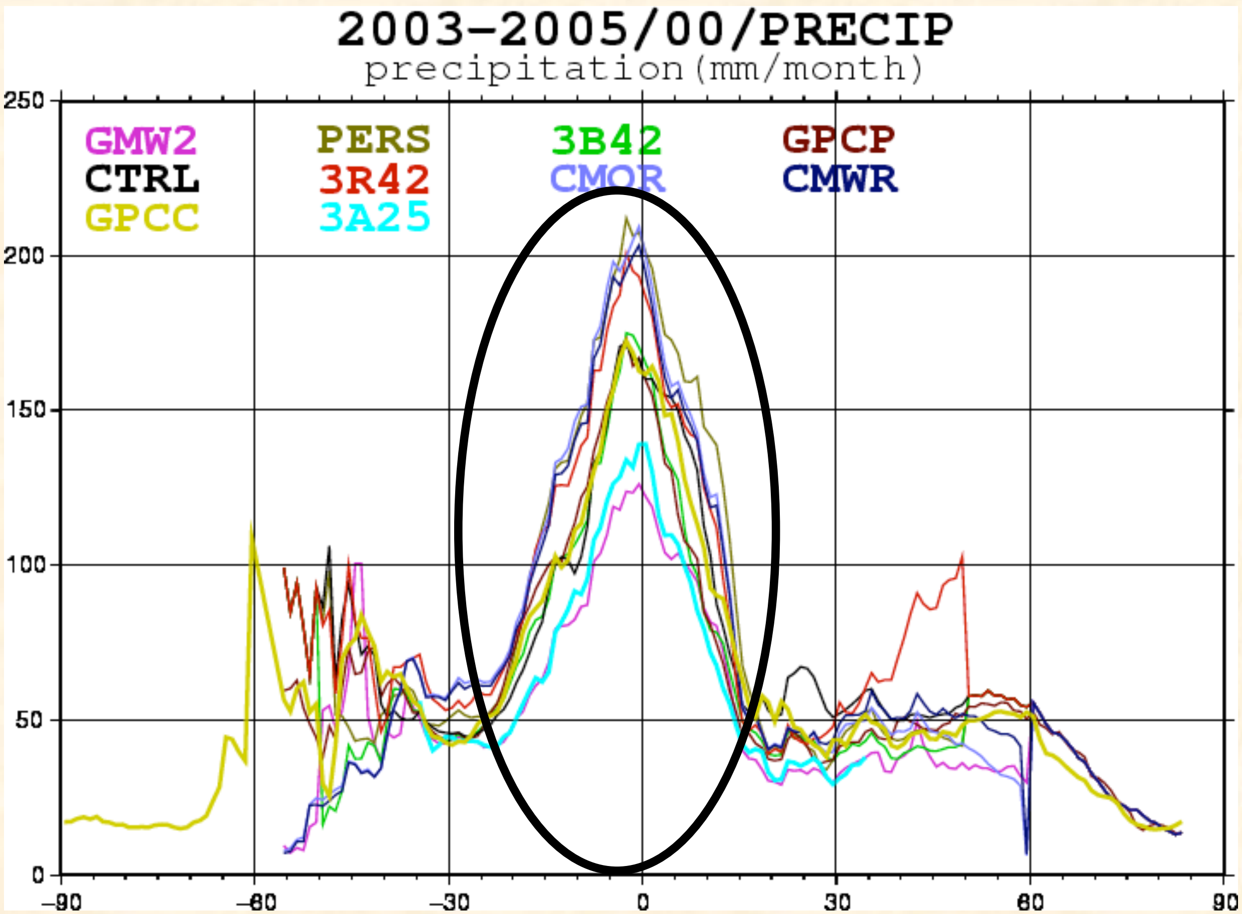
Intercomparison of HRPPs (over land only)

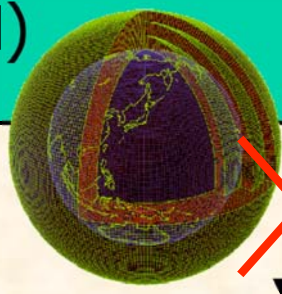
- Significant difference in Tropics (peak rainfall around the equator.)
  - high (200mm/month) 3B42RT, PERSIANN, CMORPH, …
  - moderate (170mm/month) 3B42, GPCP1DD, JMA/GSM, (GPCC)
  - low (120mm/month) GSMaP_MWR, (TRMM/PR)



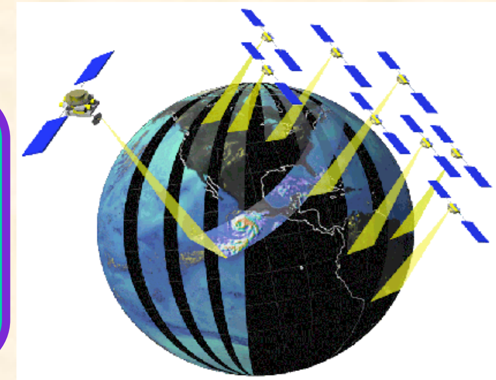
[HRPPs]
GSMaP_MWR
PERSIANN
3B42
GPCP 1DD
3B42RT
CMORPH
CPC MWCOMB
[NWP]
JMA/GSM
[Observation]
GPCC
TRMM/PR

"Yesterday's Earth"

Model Forecasts (JMA/GSM)



Satellite Precipitation Measurement



high resolution (1x1deg, 6hourly or better) product is required

Temp. etc.

Precipitation

Cloud Cover

Land Surface Model (Iso-MATSIRO)

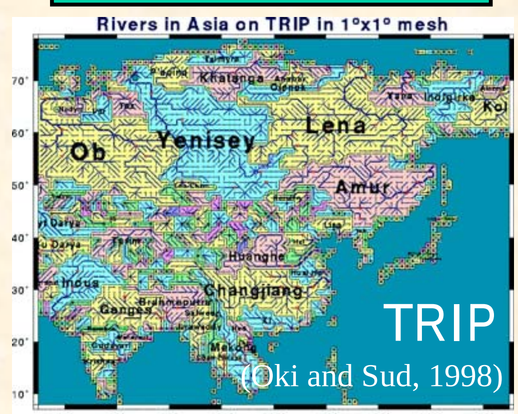
Radiation

Runoff

Soil moisture

Digital River (TRIP)

River discharge



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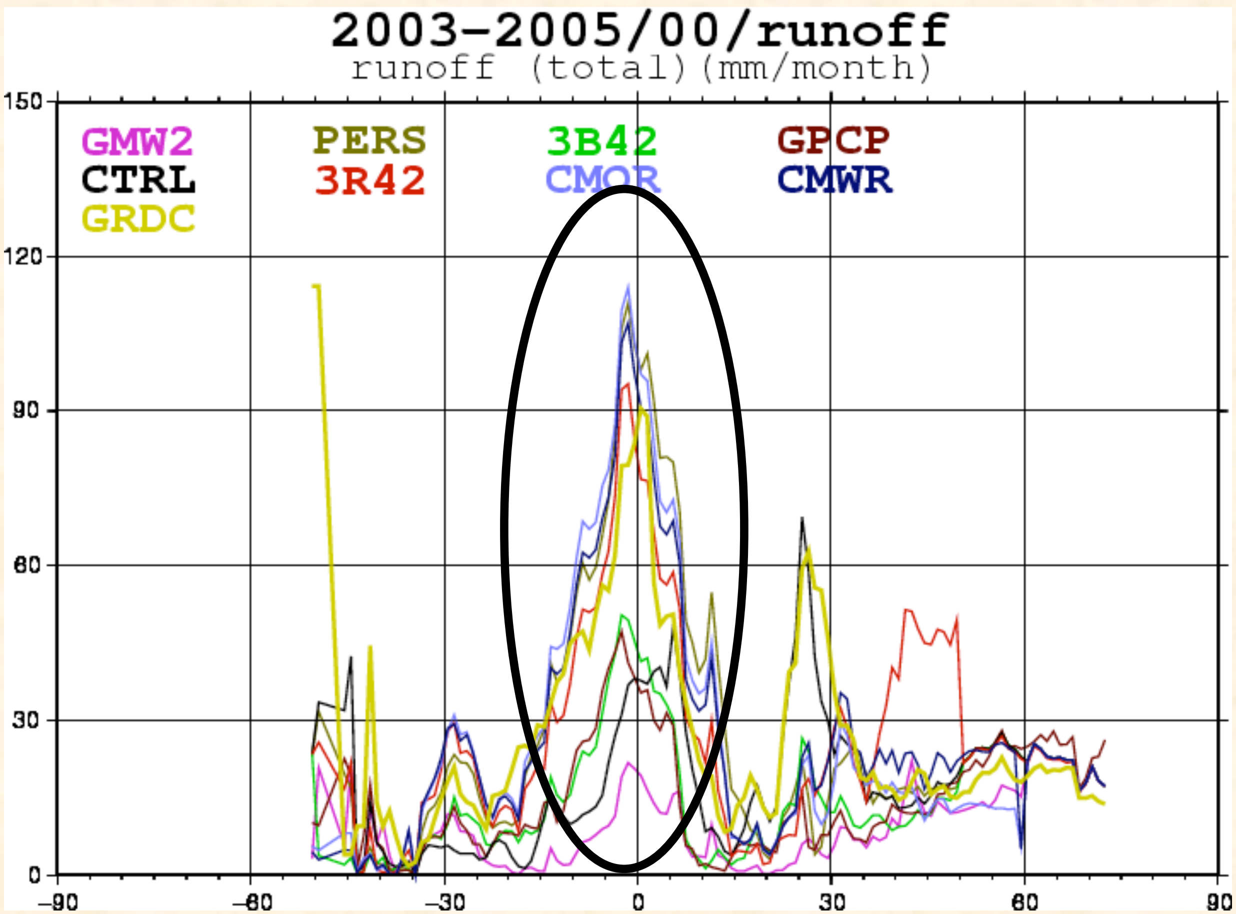
Inter comparison of runoff

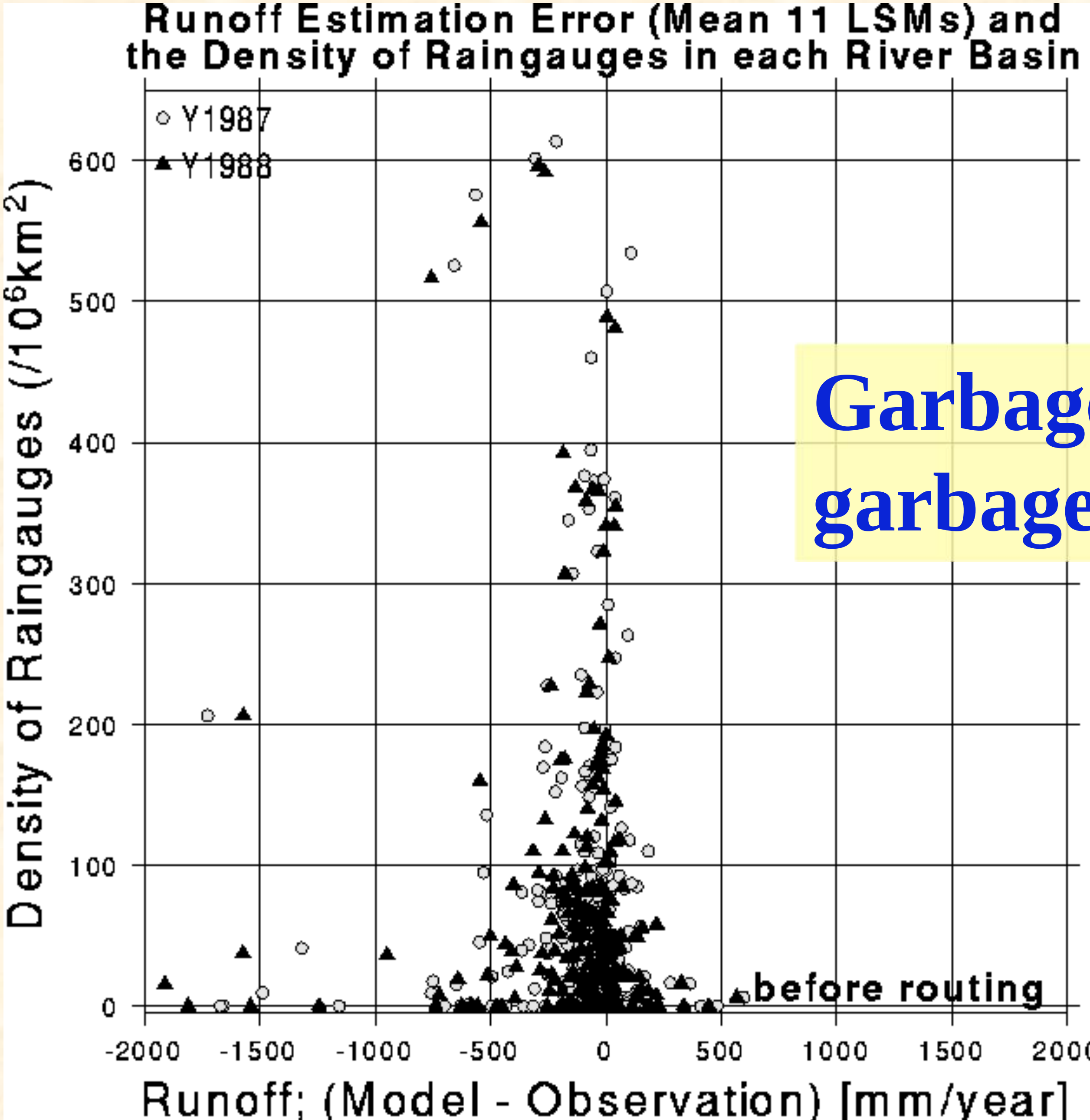
(over land and where river discharge data is available)

- **Difference is more apparent in runoff than in precipitation**
- **Compared with UNH-GRDC based on river discharge observations**
  - **In tropics, 3B42RT, PERSIANN, CMORPH are similar to observations.**
  - **In 15-30N, JMA/GSM is the best, others are underestimating.**



[HRPPs]
GSMaP_MWR
PERSIANN
3B42
GPCP 1DD
3B42RT
CMORPH
CPC MWCOMB
[NWP]
JMA/GSM
[“Observation”]
UNH_GRDC

Network Availability of In-situ Observation

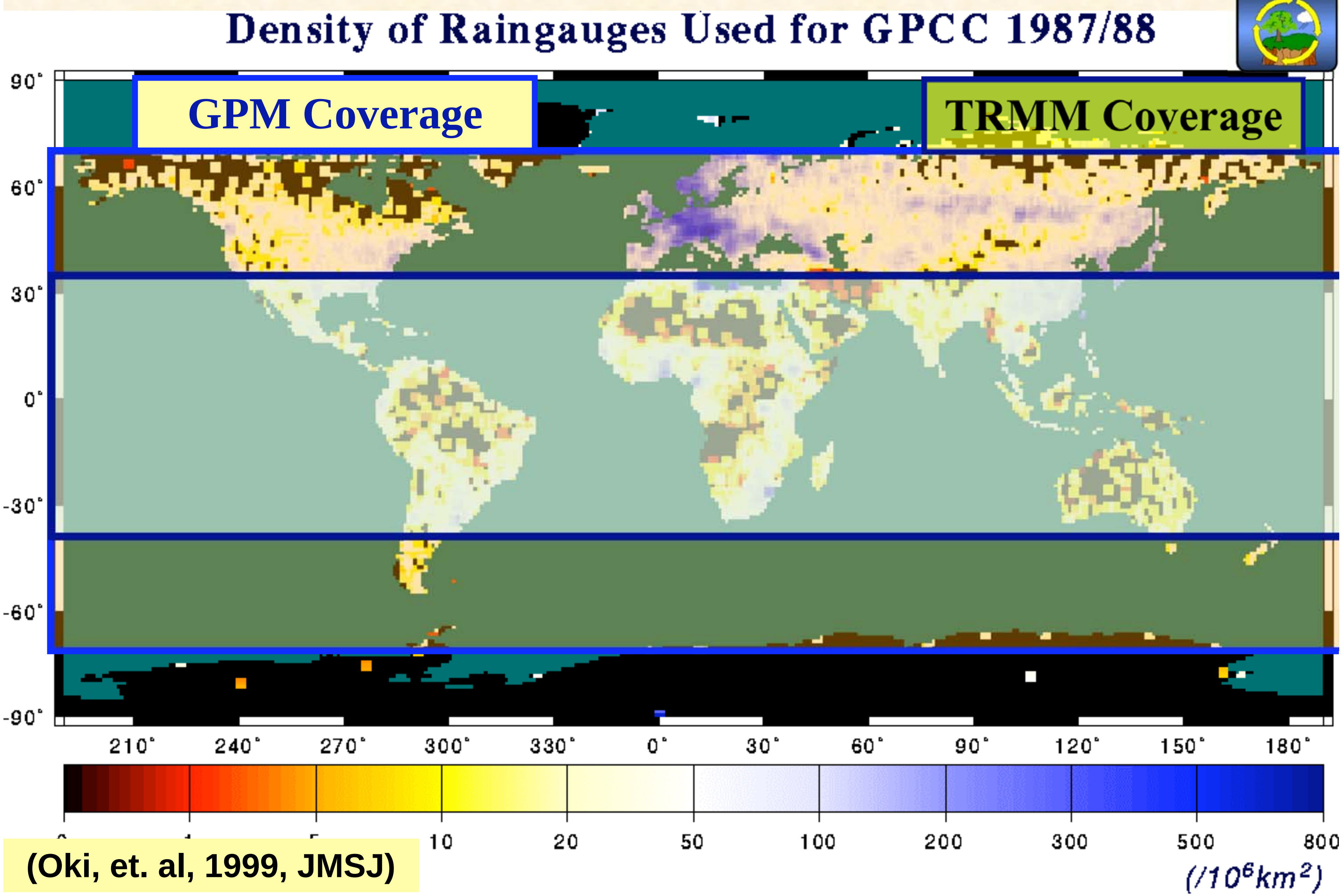


Garbage in & garbage out!

Simulation Error

(Oki, et. al, *JMSJ*, 1999)

Spatial Coverage of TRMM and GPM



(Oki, et. al, 1999, JMSJ)

Messages (1/2)

- Kevin is right: we need to update our view on the global water cycles by the latest information available.
- Global dataset is there:
  - http://gswp2.tkl.iis.u-tokyo.ac.jp/gswp2/
- (even uncertain) Estimates on the global water cycle helps social perception on the world water issues.
- Multi-decadal data may be required for robust trend detections.

Messages (2/2)

- **Real time prediction system is promising to promote hydrological science.**
  - **→improving the model capability “everyday”**
  - **+ensemble forecast, assimilation, …**
- **Un-biased precipitation data is demanded for better estimation of water cycles.**
- **Opportunities in “Not from RS” variables**
  - **population, irrigation, reservoir, …**
- **Integrated Analysis**
  - **Isotopic ratio, tagged water vapor transport, …**
  - **Incorporating with anthropogenic activities**

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For successes in research projects

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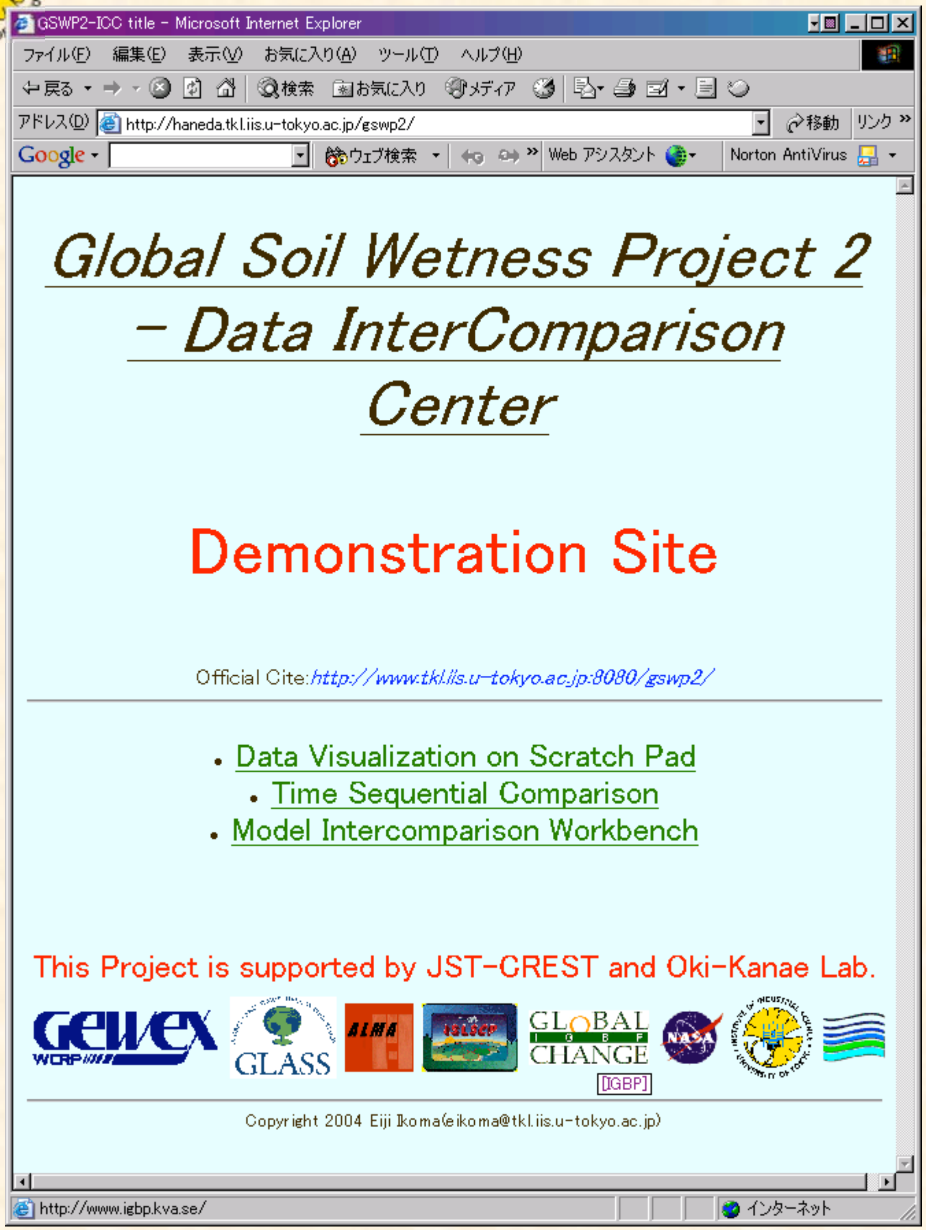


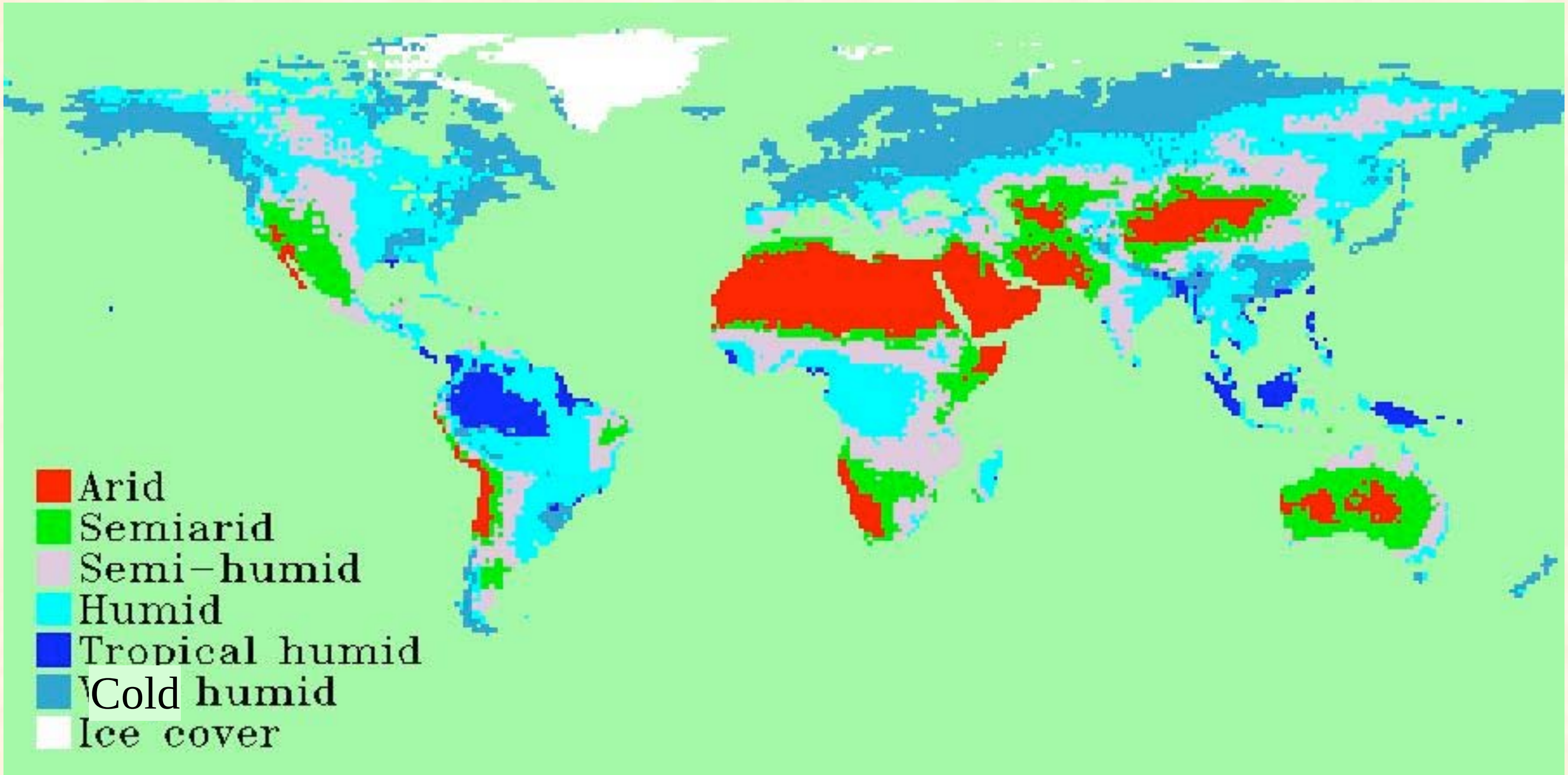
SGI ONYX4
UltimateVision

More than 1PB of
Data Archiver

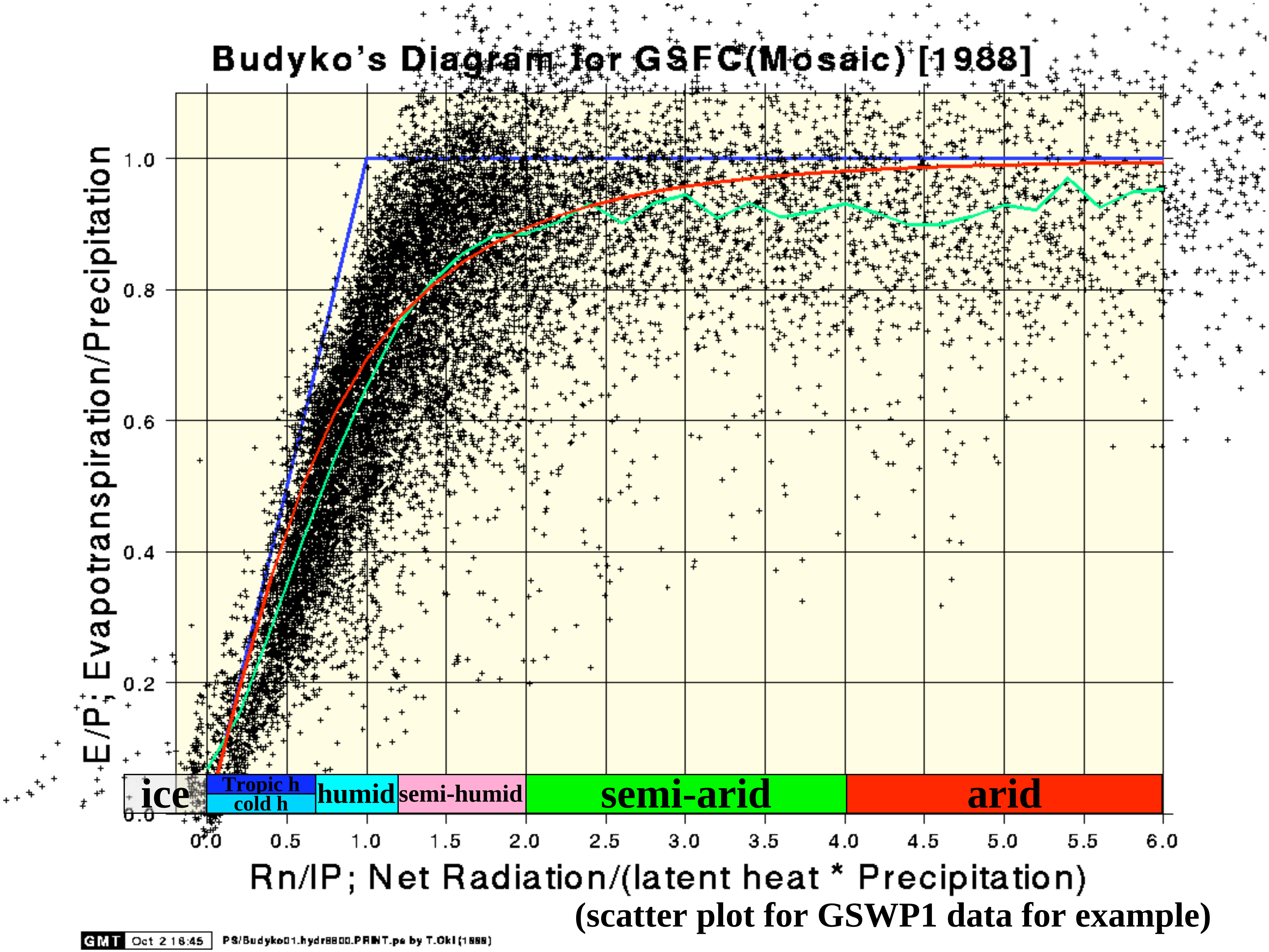
GSWP2-ICC/DDC
Top page

http://gswp2.tkl.iis.u-tokyo.ac.jp/gswp2/

Climatic Zones delineated by Budyko's Aridity Index (BAI)



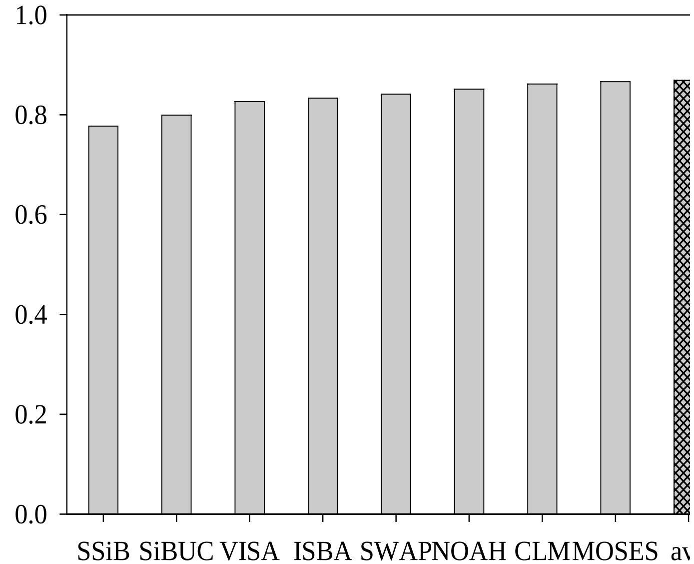
(Budyko Aridity Index=Rn/lP)

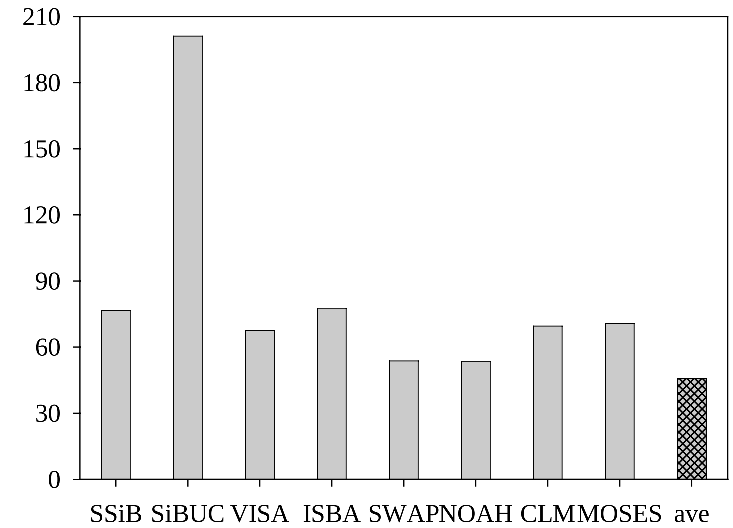


(scatter plot for GSWP1 data for example)

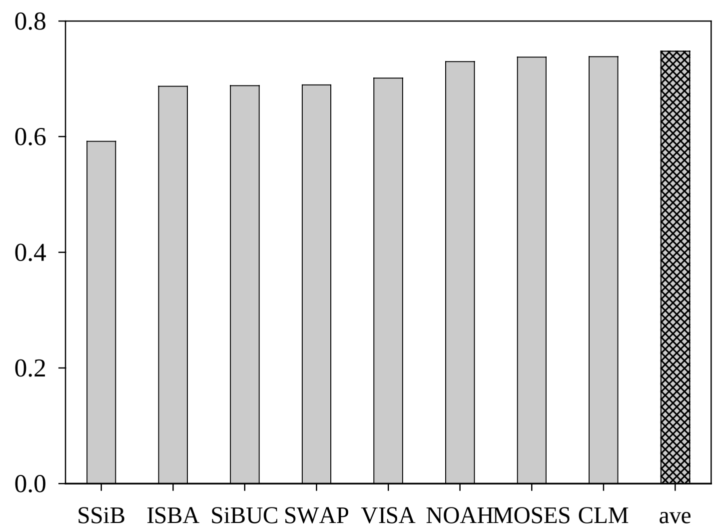
Validation of GSWP-2 1m Column Soil Moisture (IL, GSMDB)

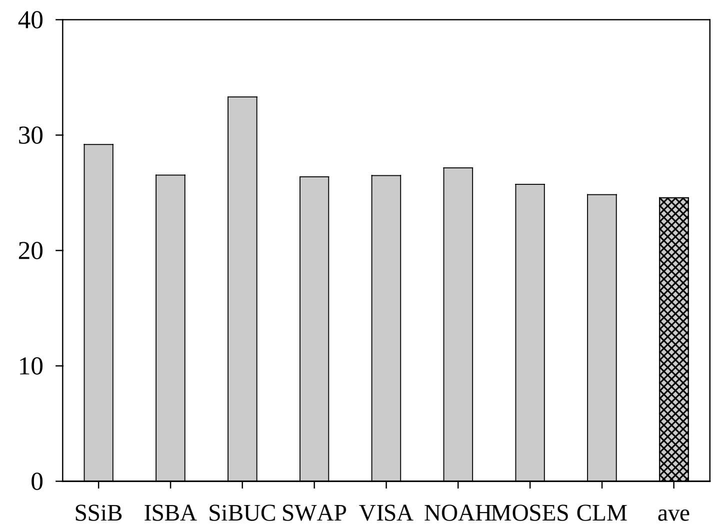
Total Field (1m, 1986-1995)





Anomaly (1m, 1986-1995)

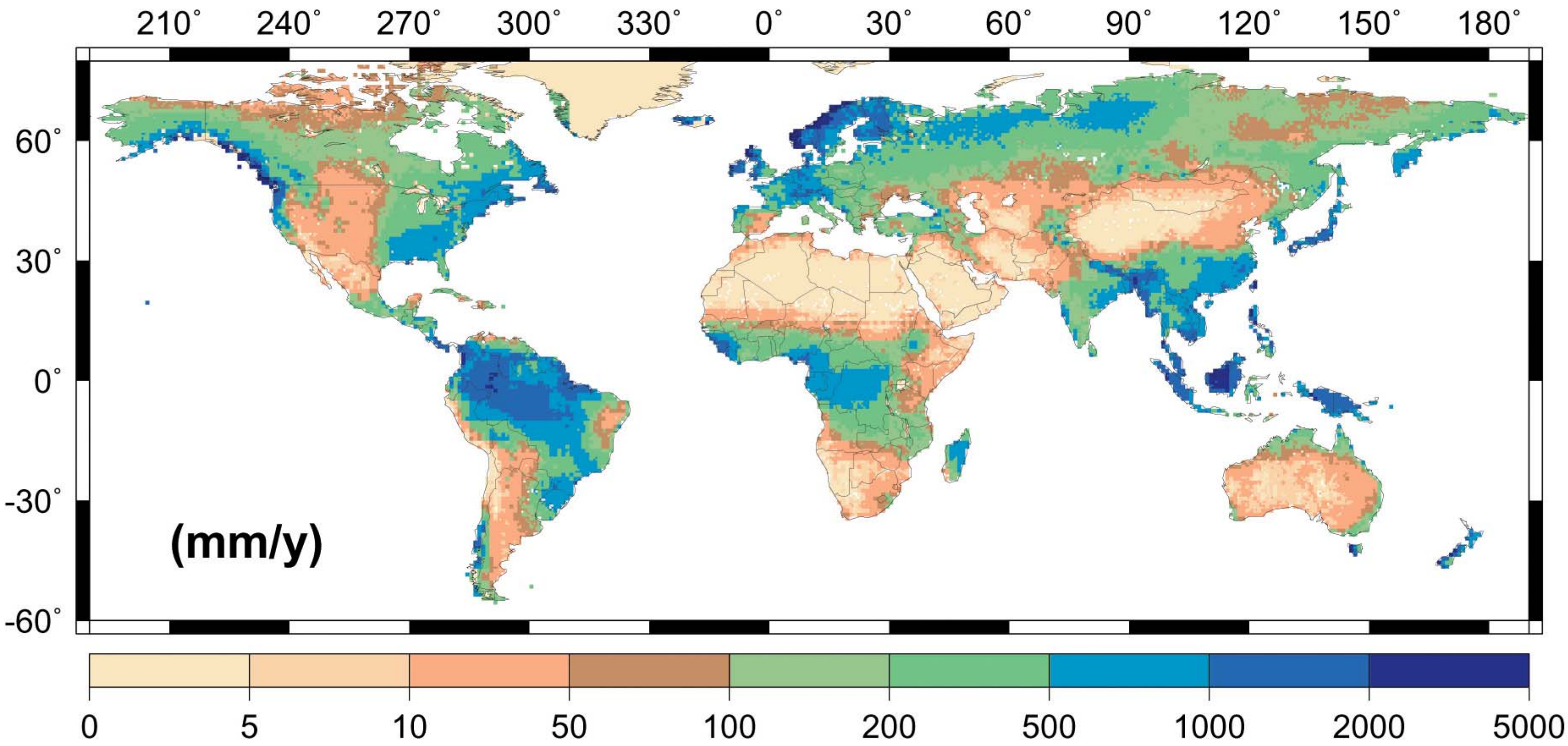




(Dirmeyer, et. al, 2005)

A

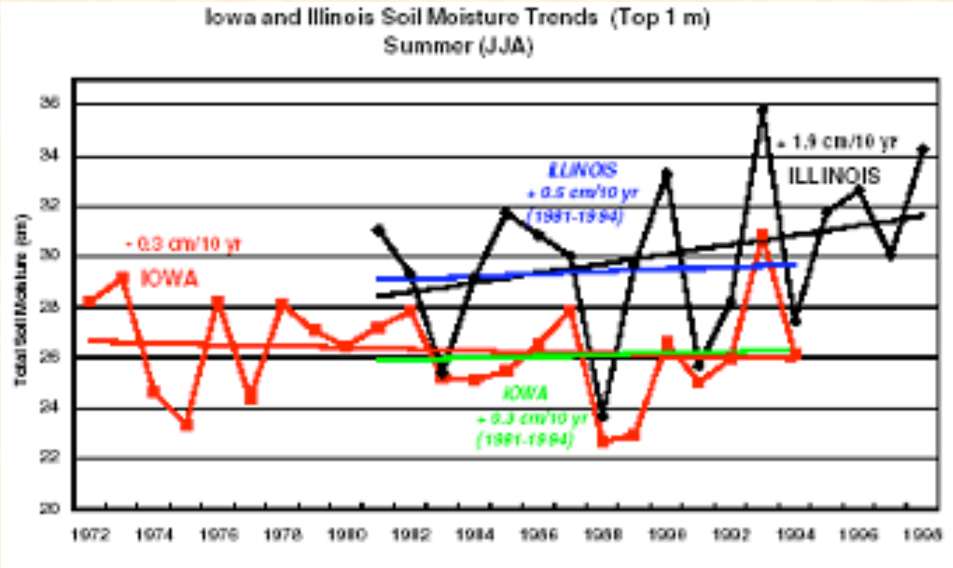
Annual Runoff

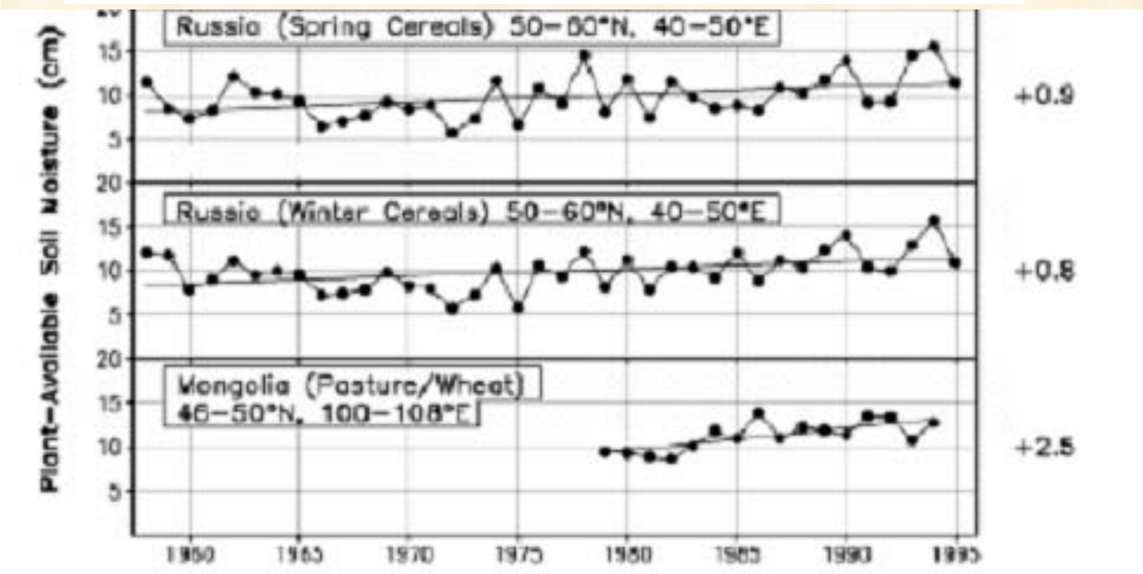


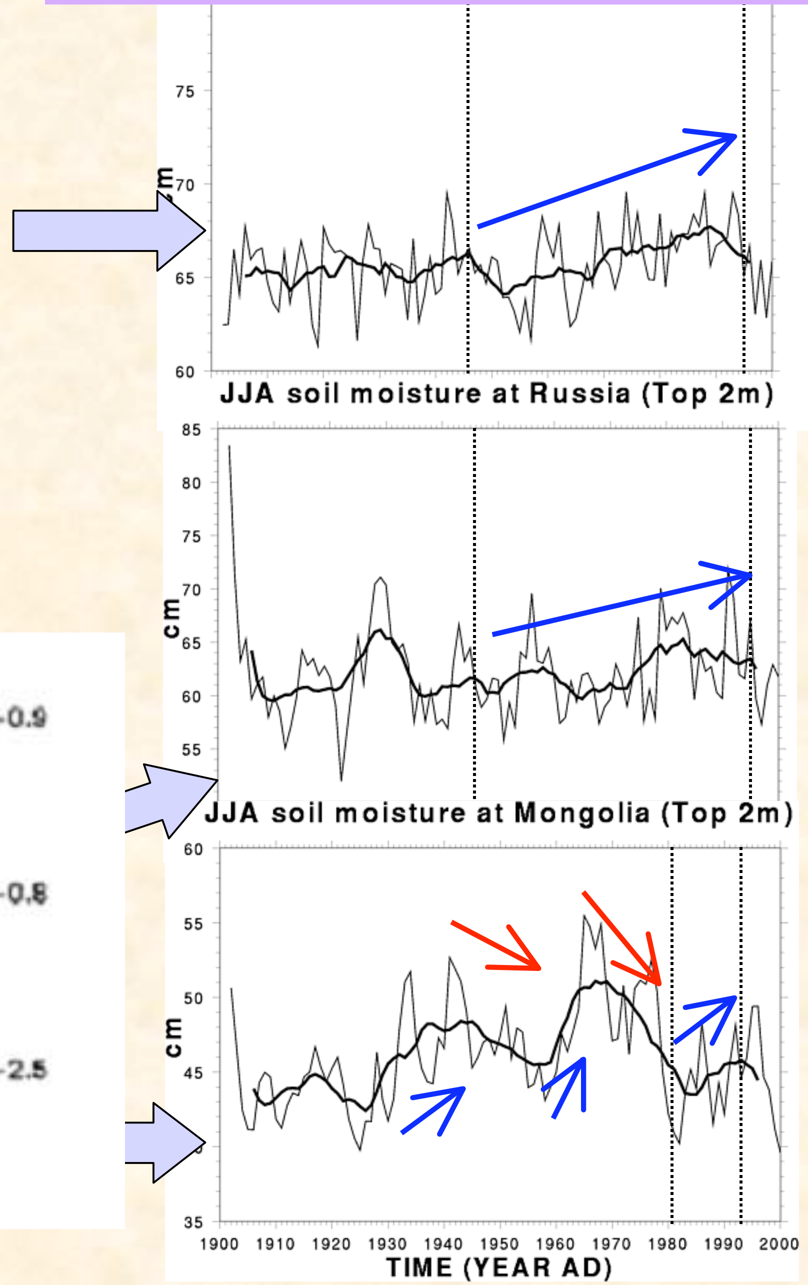
(Oki and Kanae, *Science*, 2006)

Soil Moisture in Summer has an increasing trend (Robock, 2000)

Simulation shows similar trends in each region

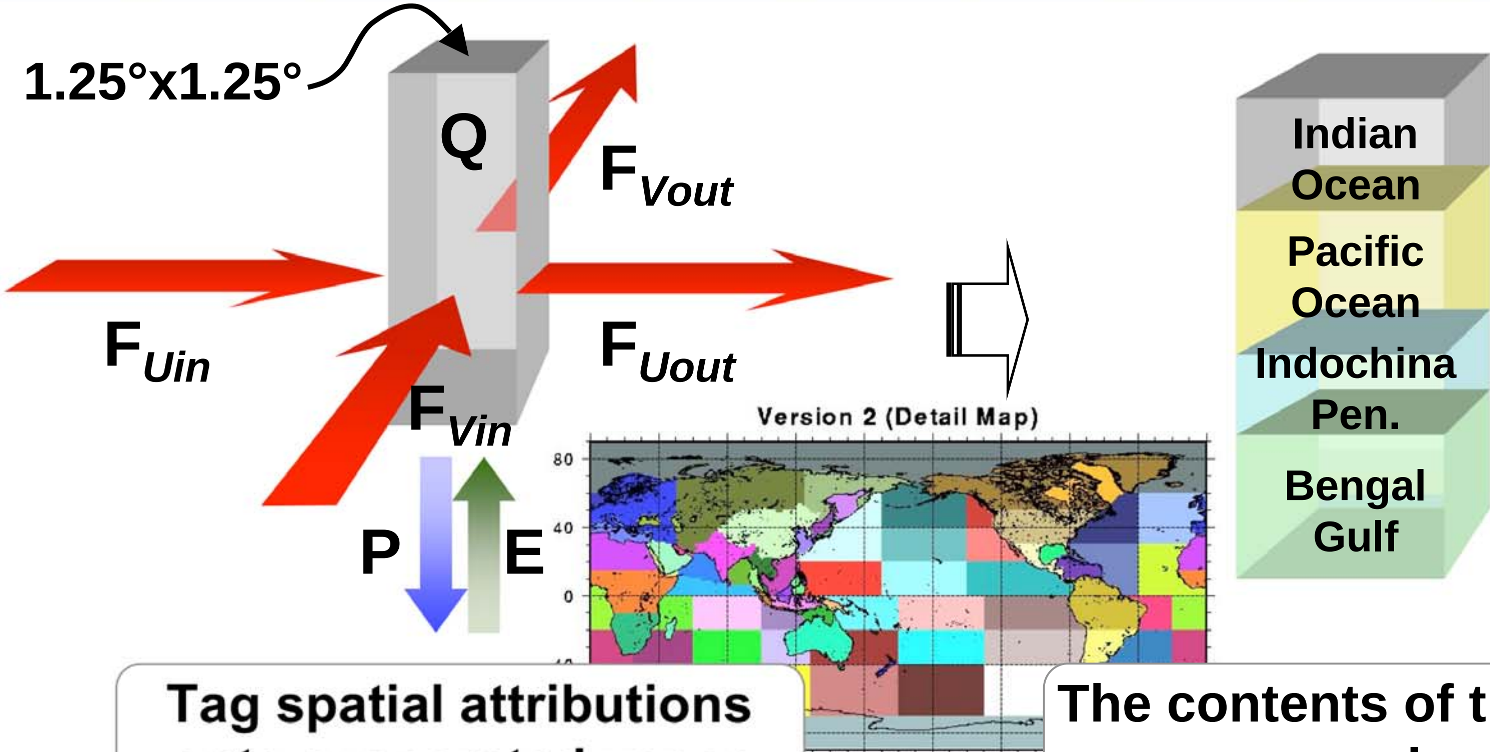






(Hirabayashi *et al*., *JGR*, 2005)

Colored Moisture Analysis (CMA)



Tag spatial attributions onto evaporated vapor

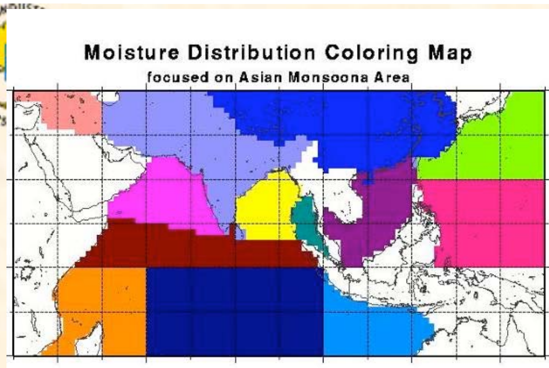
The contents of the water are analyzed.

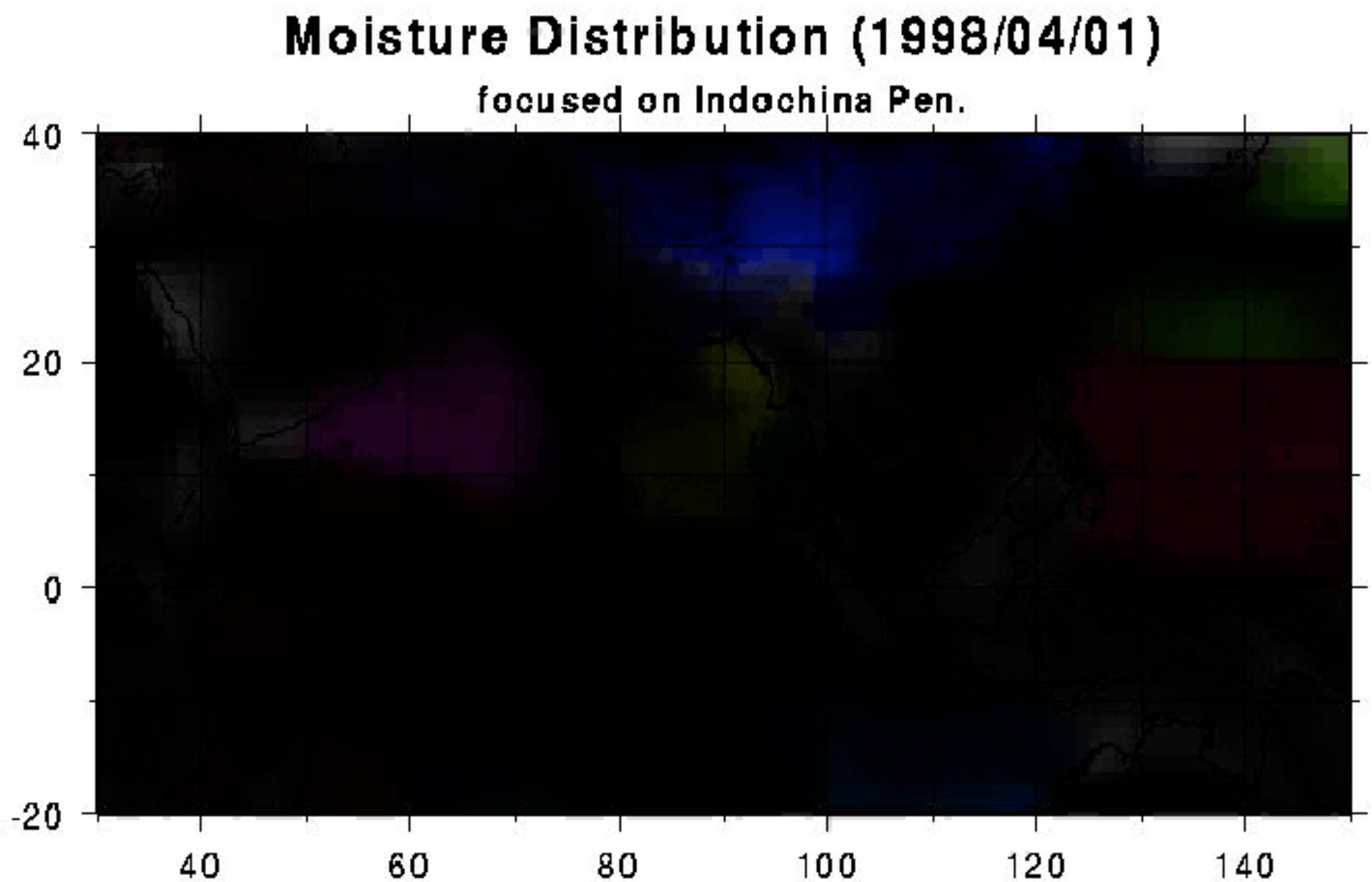
Used Data: GAME-reanalysis Ver1.5

Precipitation, Evaporation, Precipitable water, and Vertical integrated Moisture Fluxes (U, V)

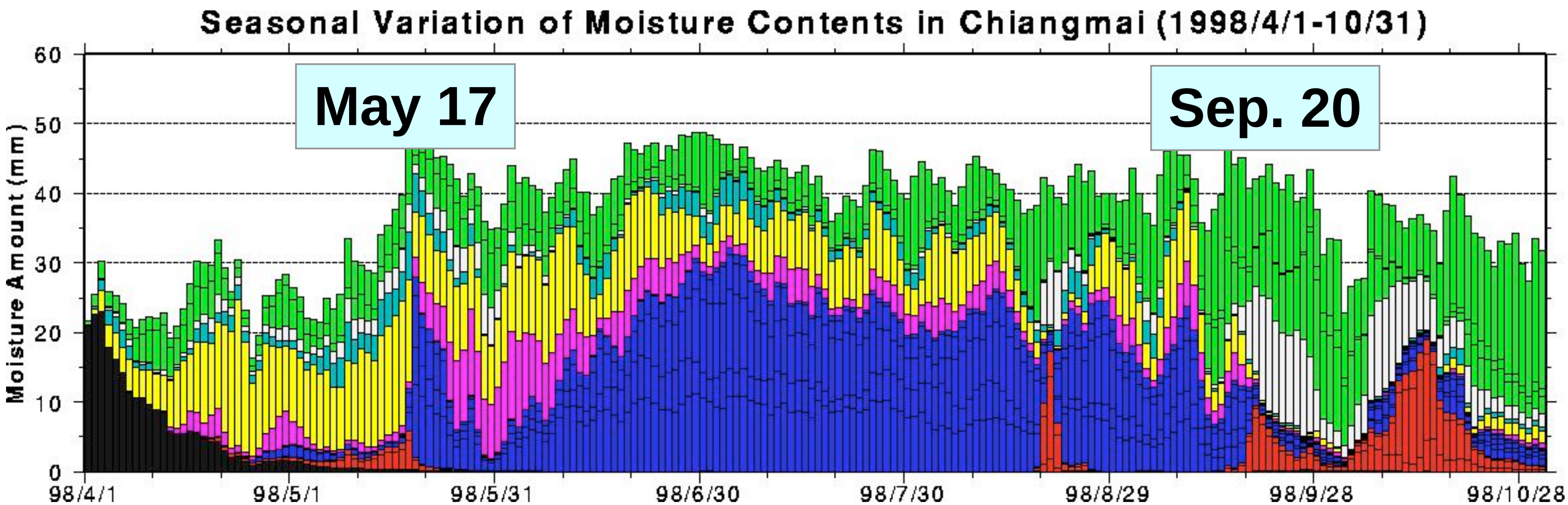
(Yoshimura *et al.*, *JMSJ*, 2005)

CMA Result 2-1:
80 tags, same period, A.M. area





CMA result 3: Temporal variation (98/04/01~10/31) in Chiangmai



Land	Indian O.	Pacific O.	Bengal G.
Arabic S.	Andaman S.	Etc.	Initial

Sudden Increase of Indian O. ← Onset

Withdrawal → **Sudden Decrease of Indian O.**

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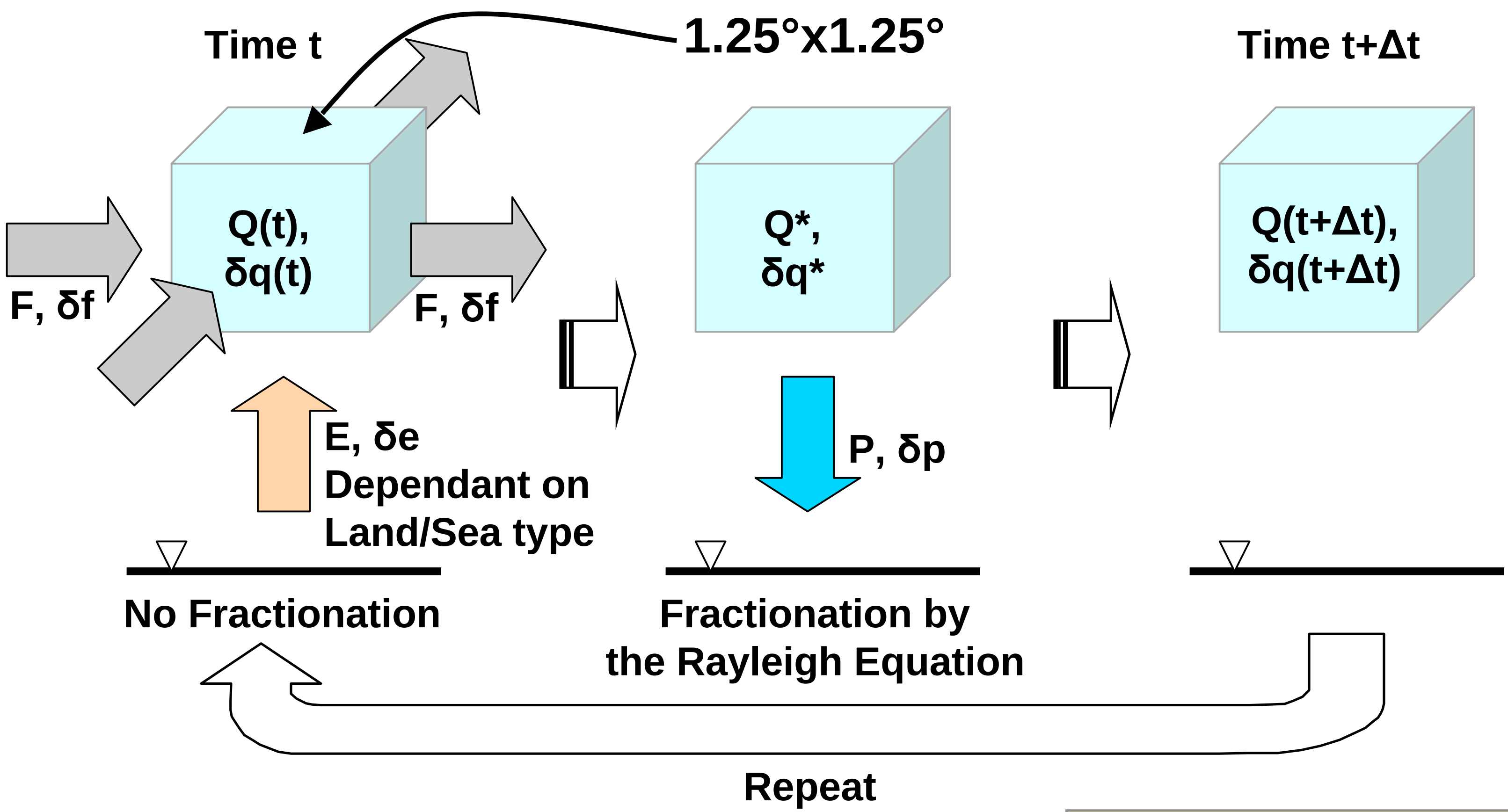
Vertically Integrated 2-dimensional Isotope Circulation Model (ICM)



α=1.0094, δe_{land}(>40°N,S)=-15‰
δe_{sea}=-9.4‰, δe_{land}(<40°N,S)=-10‰

MATSIRO with Isotopic processes in Today's Earth

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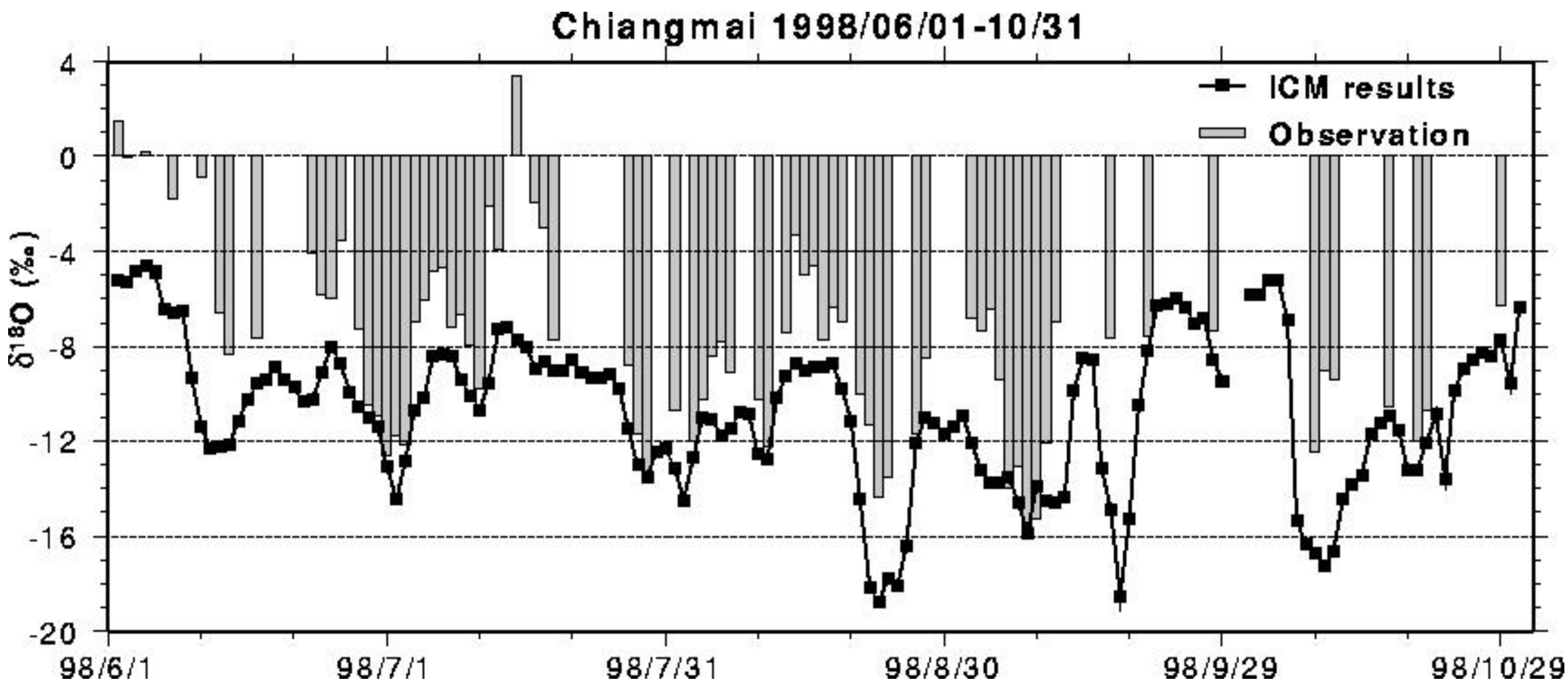
ICM Result Validation (Chiangmai, 1998)



ICM reproduced the daily variability of the precipitation Isotope!! (R=0.76)

(Yoshimura *et al.*, *JGR*, 2003)